

# The Signatures of Baryon Acoustic Oscillations and Primordial Non-gaussianities in the Lyman-alpha forest

**Shirley Ho**

**Lawrence Berkeley National Laboratory**

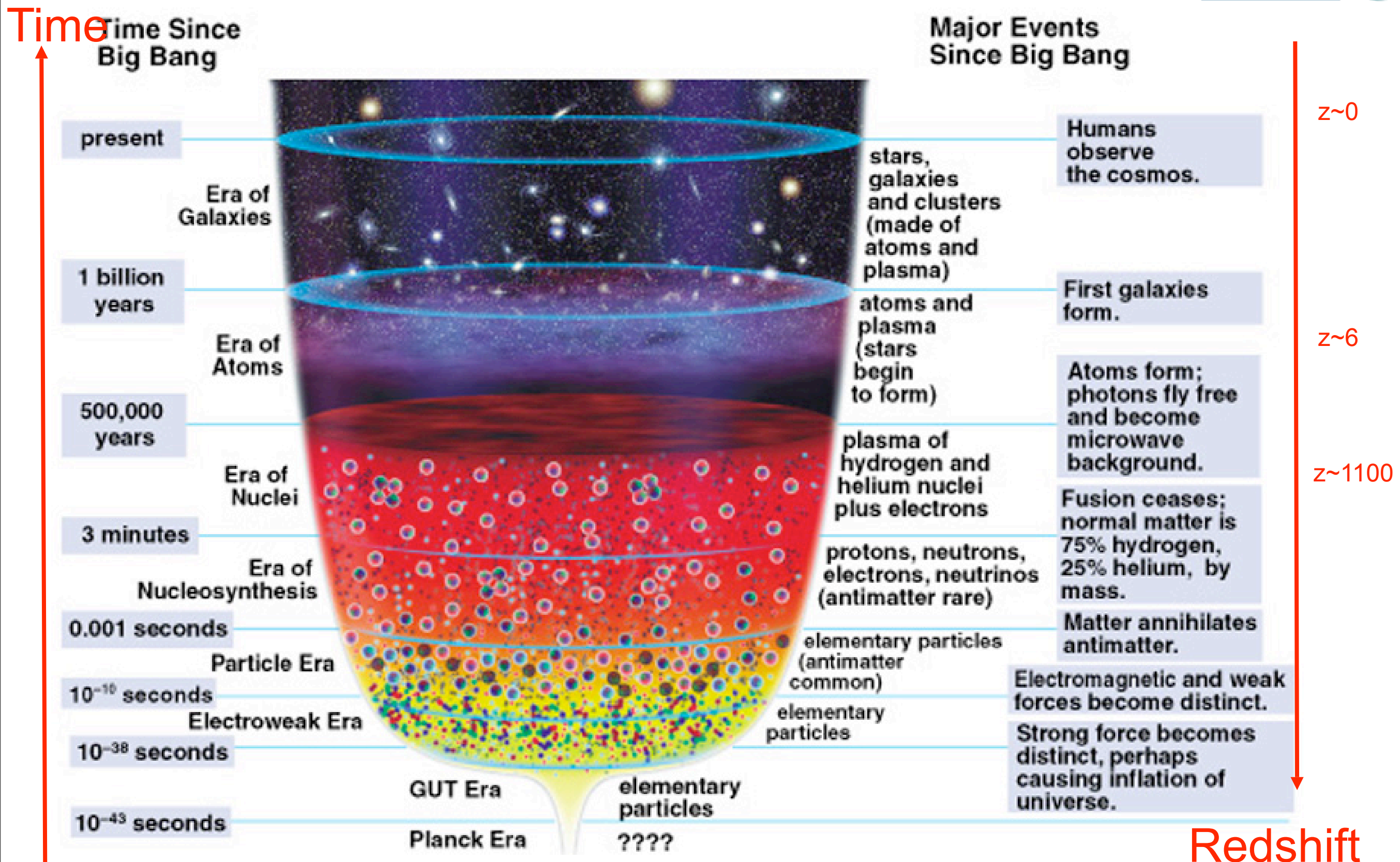
**With collaborators:**

**Anze Slosar, Martin White, Uros Seljak,  
Vincent Desjacques and Thibaut Louis**

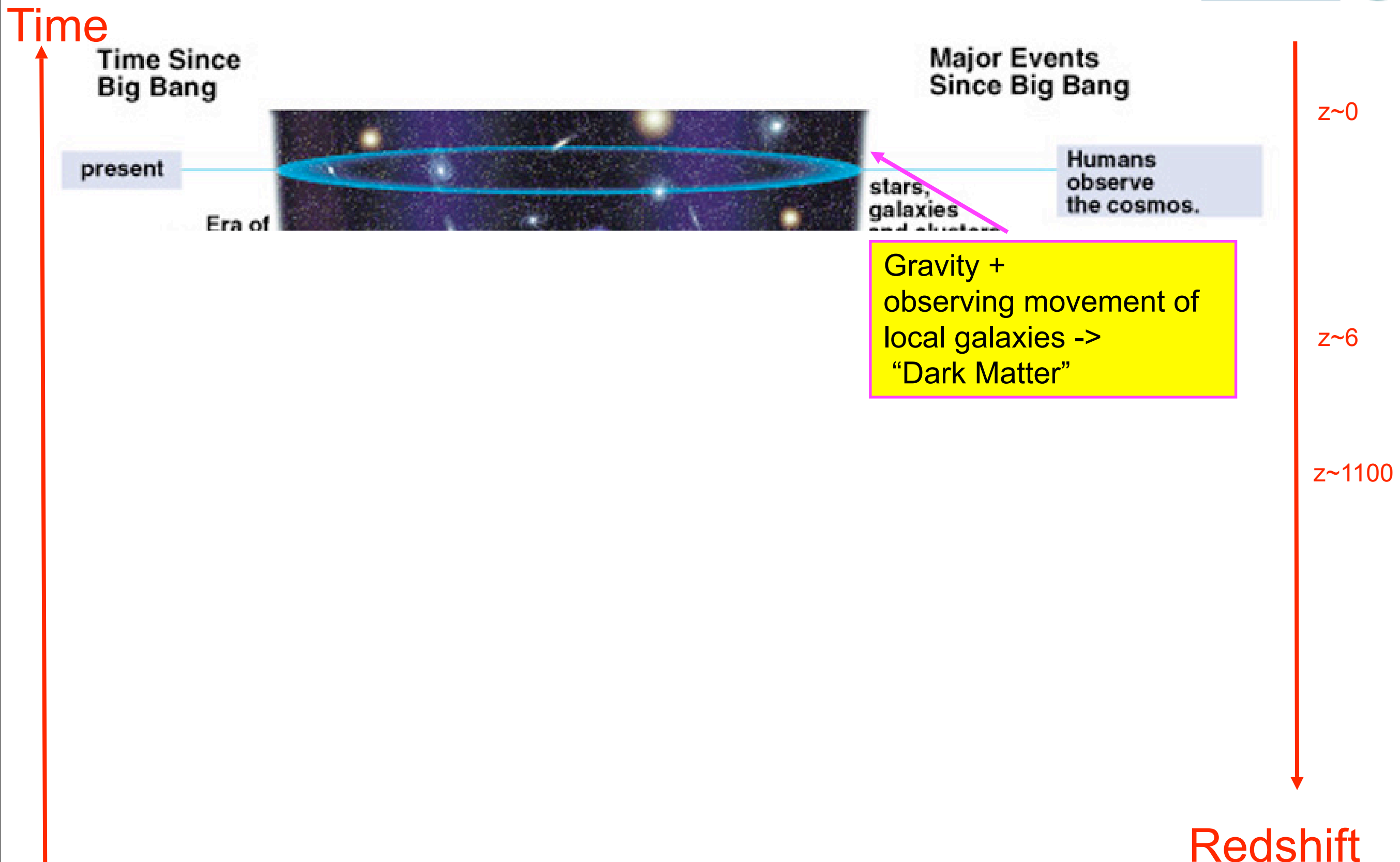
**10/5/09, Fermilab**

- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations**
    - Dark Energy
  - **Scale Dependent Bias**
    - Primordial Non-gaussianities ( $f_{\text{nl}}$ )
- **Conclusion**

# Motivations



# Motivations





# Motivations

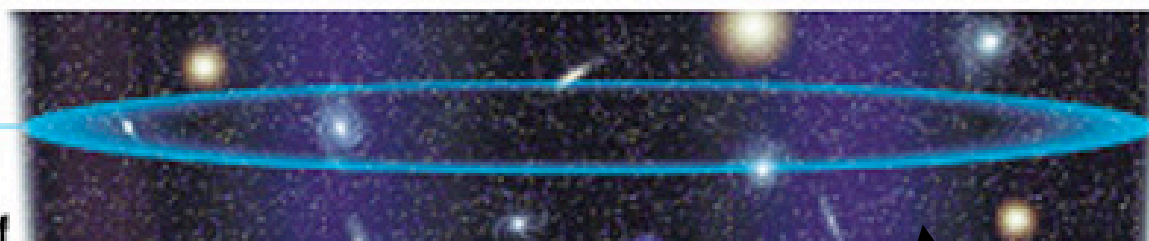
Time

Time Since  
Big Bang

Major Events  
Since Big Bang

present

Era of

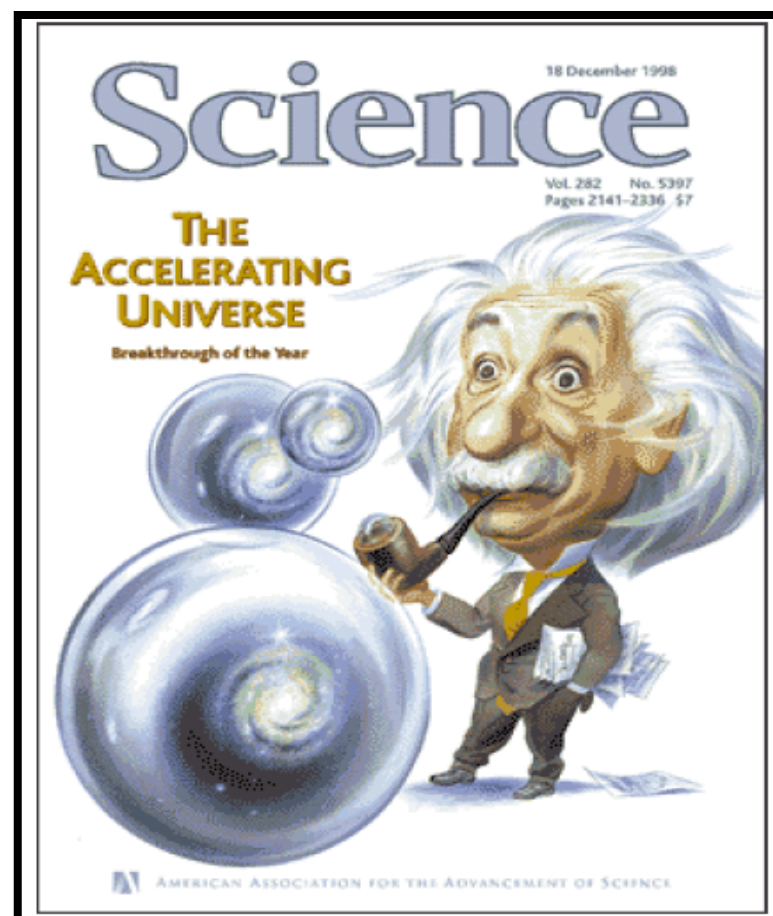


stars,  
galaxies  
and clusters

Humans  
observe  
the cosmos.

Gravity +  
observing movement of  
local galaxies ->  
“Dark Matter”

Distant supernovas appear fainter  
than expected (1998)->  
Universe is accelerating ->  
Cosmological Constant?  
Dark Energy?



$z \sim 0$

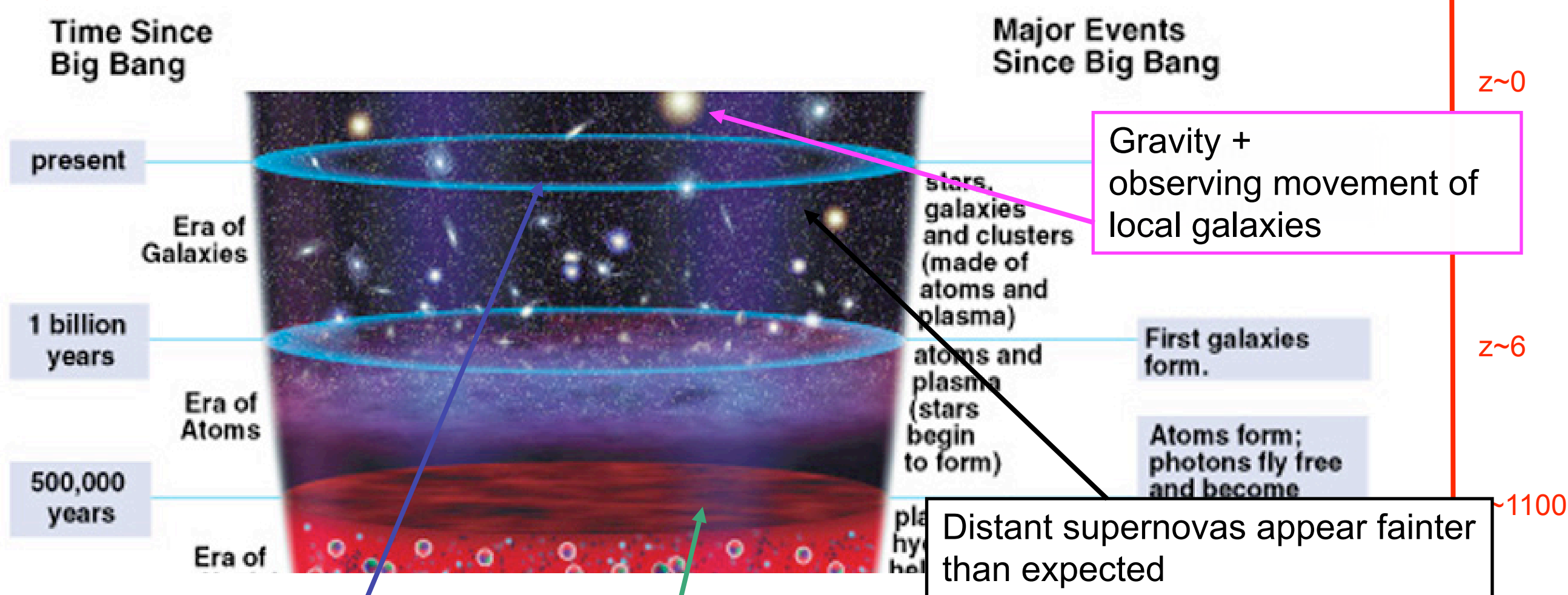
$z \sim 6$

$z \sim 1100$

Redshift

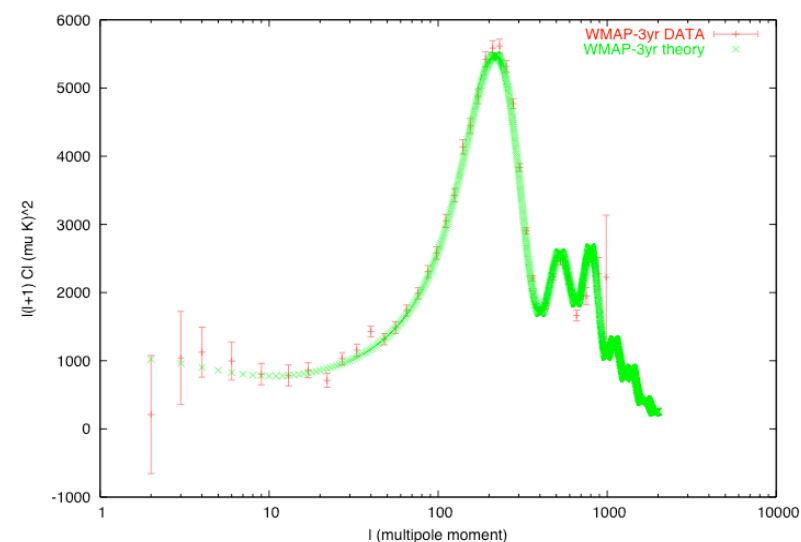
# Motivations

Time



Observations of how galaxies cluster

Observations of Cosmic Microwave Background (CMB)  
 -> angular powerspectrum of temperature anisotropies



Redshift

# Motivations

Time

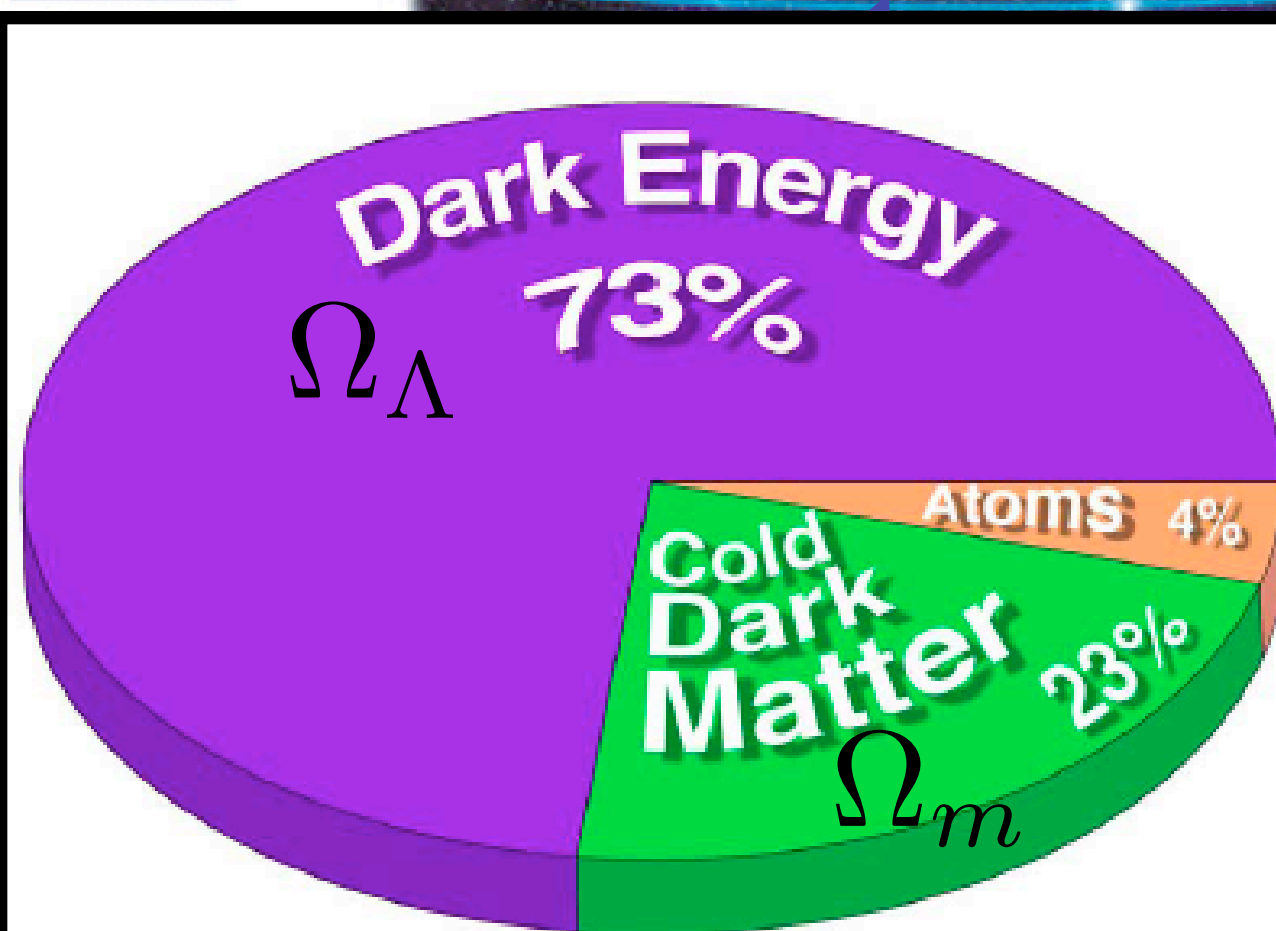
Time Since  
Big Bang

Major Events  
Since Big Bang

$z \sim 0$

present

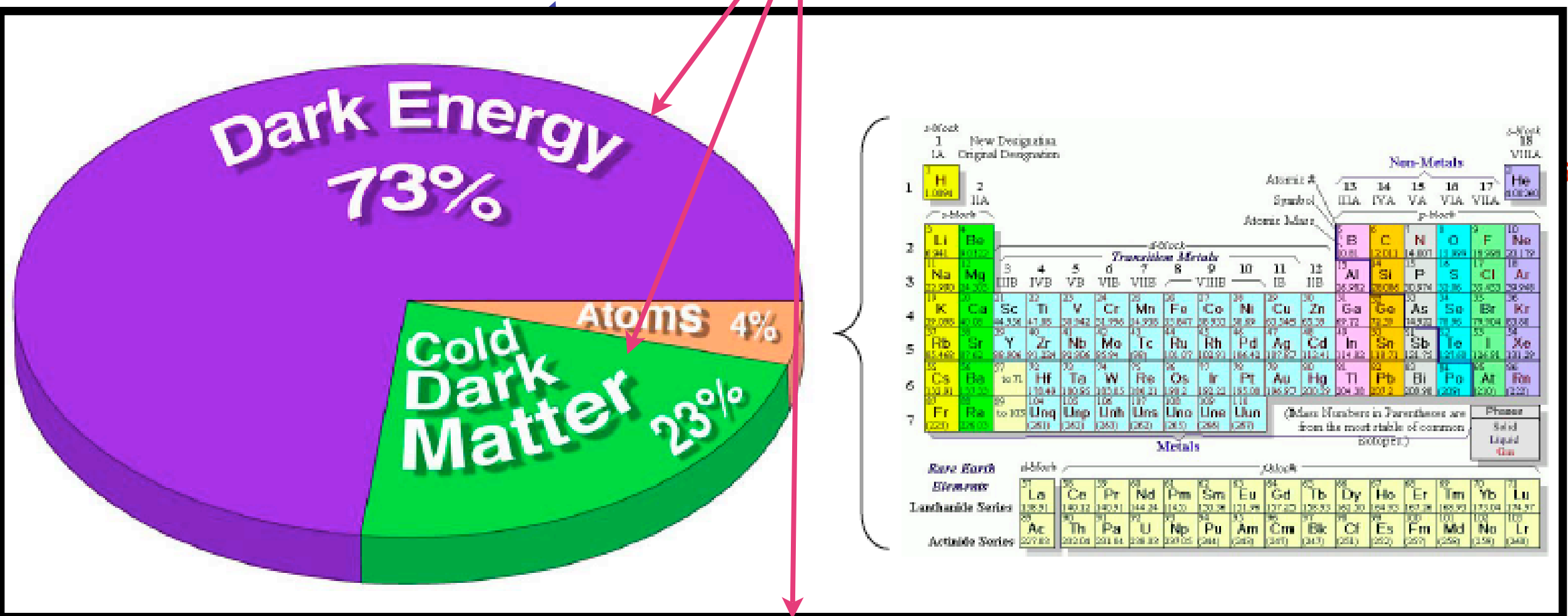
Gravity +  
observing movement of



1		New Designation										Original Designation										Non-Metals										18																				
1A																																VIII																				
1		H										He																				1																				
1.008																																1.008																				
2		IIA																														2																				
3		III										IV										V										VI										VII										3
4		IV										V										VI										VII										VIII										4
5		V										VI										VII										VIII										IX										5
6		VI										VII										VIII										IX										X										6
7		VII										VIII										IX										X										XI										7
8		VIII										IX										X										XI										XII										8
9		IX										X										XI										XII										XIII										9
10		X										XI										XII										XIII										XIV										10
11		XI										XII										XIII										XIV										XV										11
12		XII										XIII										XIV										XV										XVI										12
13		IIB										IIB										IIB										IIB										IIB										13
14		IIB										IIB										IIB										IIB										IIB										14
15		IIB										IIB										IIB										IIB										IIB										15
16		IIB										IIB										IIB										IIB										IIB										16
17		IIB										IIB										IIB										IIB										IIB										17
18		IIB										IIB										IIB										IIB										IIB										18
19		IIB										IIB										IIB										IIB										IIB										19
20		IIB										IIB										IIB										IIB										IIB										20
21		IIB										IIB										IIB										IIB										IIB										21
22		IIB										IIB										IIB										IIB										IIB										22
23		IIB										IIB										IIB										IIB										IIB										23
24		IIB										IIB										IIB										IIB										IIB										24
25		IIB										IIB										IIB										IIB										IIB										25
26		IIB										IIB										IIB										IIB										IIB										26
27		IIB										IIB										IIB										IIB										IIB										27
28		IIB										IIB										IIB										IIB										IIB										28
29		IIB										IIB										IIB										IIB										IIB										29
30		IIB										IIB										IIB										IIB										IIB										30
31		IIB										IIB										IIB										IIB										IIB										31
32		IIB										IIB										IIB										IIB										IIB										32
33		IIB										IIB										IIB										IIB										IIB										33
34		IIB										IIB										IIB										IIB										IIB										34
35		IIB										IIB										IIB										IIB										IIB										35
36		IIB										IIB										IIB										IIB										IIB										36
37		IIB										IIB										IIB										IIB										IIB										37
38		IIB										IIB										IIB										IIB										IIB										38
39		IIB										IIB										IIB										IIB										IIB										39
40		IIB										IIB										IIB										IIB										IIB										40
41		IIB										IIB										IIB										IIB										IIB										41
42		IIB										IIB										IIB										IIB										IIB										42
43		IIB										IIB										IIB										IIB										IIB										43
44		IIB										IIB										IIB										IIB										IIB										44
45		IIB										IIB										IIB										IIB										IIB										45
46		IIB										IIB										IIB										IIB										IIB										46
47		IIB										IIB										IIB										IIB										IIB										47
48		IIB										IIB										IIB										IIB										IIB										48
49		IIB										IIB										IIB										IIB										IIB										49
50		IIB										IIB										IIB										IIB										IIB										50
51		IIB										IIB										IIB										IIB										IIB										51
52		IIB										IIB										IIB										IIB										IIB										52
53		IIB										IIB										IIB										IIB										IIB										53
54		IIB										IIB										IIB										IIB										IIB										54
55		IIB										IIB										IIB										IIB										IIB										55
56		IIB										IIB										IIB										IIB										IIB										56
57		IIB										IIB										IIB										IIB										IIB										57
58		IIB										IIB										IIB										IIB										IIB										58
59		IIB										IIB										IIB										IIB										IIB										59
60		IIB										IIB										IIB										IIB										IIB										60
61		IIB										IIB										IIB										IIB										IIB										61
62		IIB										IIB										IIB										IIB										IIB										62
63		IIB										IIB										IIB										IIB										IIB										63
64		IIB										IIB										IIB										IIB										IIB										64
65		IIB										IIB										IIB										IIB										IIB										65
66		IIB										IIB										IIB										IIB										IIB										66
67		IIB										IIB										IIB										IIB										IIB										67
68		IIB										IIB										IIB										IIB										IIB										68
69		IIB										IIB										IIB										IIB										IIB										69
70		IIB										IIB										IIB										IIB										IIB										70
71		IIB										IIB										IIB										IIB										IIB										71
72		IIB										IIB										IIB										IIB										IIB										72
73		IIB										IIB										IIB										IIB										IIB										73
74		IIB										IIB										IIB										IIB										IIB										74
75		IIB										IIB										IIB										IIB										IIB										75
76		IIB										IIB										IIB										IIB										IIB										76
77		IIB										IIB										IIB										IIB										IIB										77
78		IIB										IIB										IIB										IIB										IIB										78
79		IIB										IIB										IIB										IIB										IIB										79
80		IIB										IIB										IIB										IIB										IIB										80
81		IIB										IIB										IIB										IIB										IIB										81
82		IIB										IIB										IIB										IIB										IIB										82
83		IIB										IIB										IIB										IIB										IIB										83
84		IIB										IIB										IIB										IIB										IIB										84
85		IIB										IIB										IIB										IIB										IIB										85
86		IIB										IIB										IIB										IIB										IIB										86
87		IIB										IIB										IIB										IIB										IIB										87
88		IIB										IIB																																								

# Motivations

??



What happened at the Beginning of the Universe?

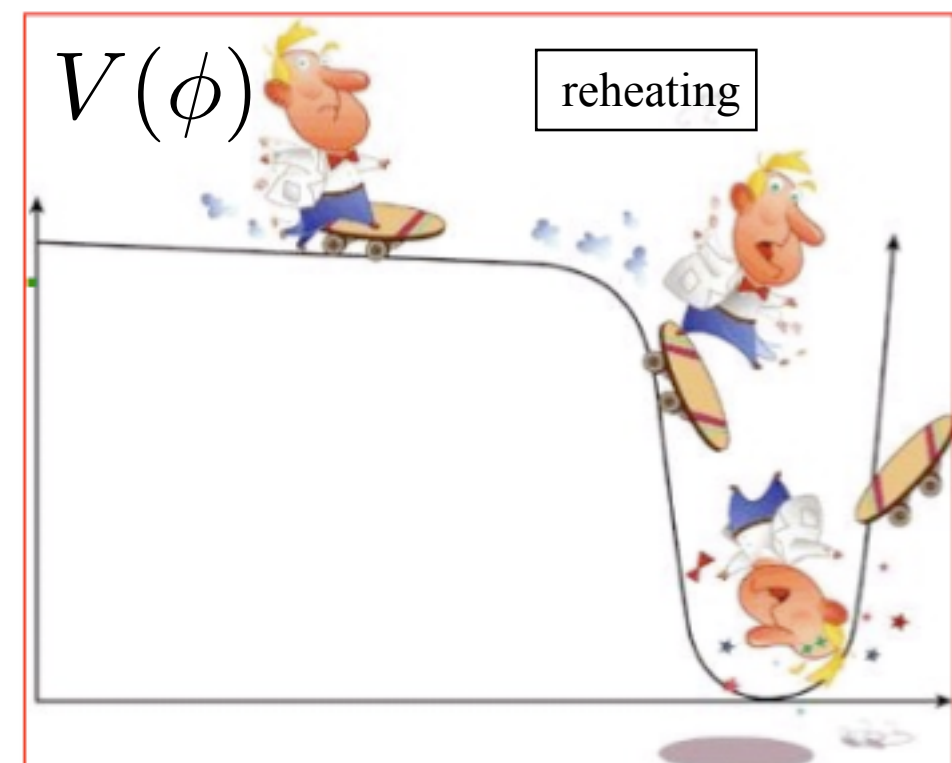
# Lyman Alpha Forest: what can it do?

## —Non-gaussianities in Early Universe

parameterize how much non-linear corrections are there to the potential

$$\Phi = \phi + f_{NL} \phi^2$$

Primordial potential (assumed to be gaussian random field)



# Lyman Alpha Forest: what can it do?

## —Non-gaussianities in Early Universe

parameterize how much non-linear corrections are there to the potential

$$\Phi = \phi + f_{NL} \phi^2$$

Primordial potential (assumed to be gaussian random field)

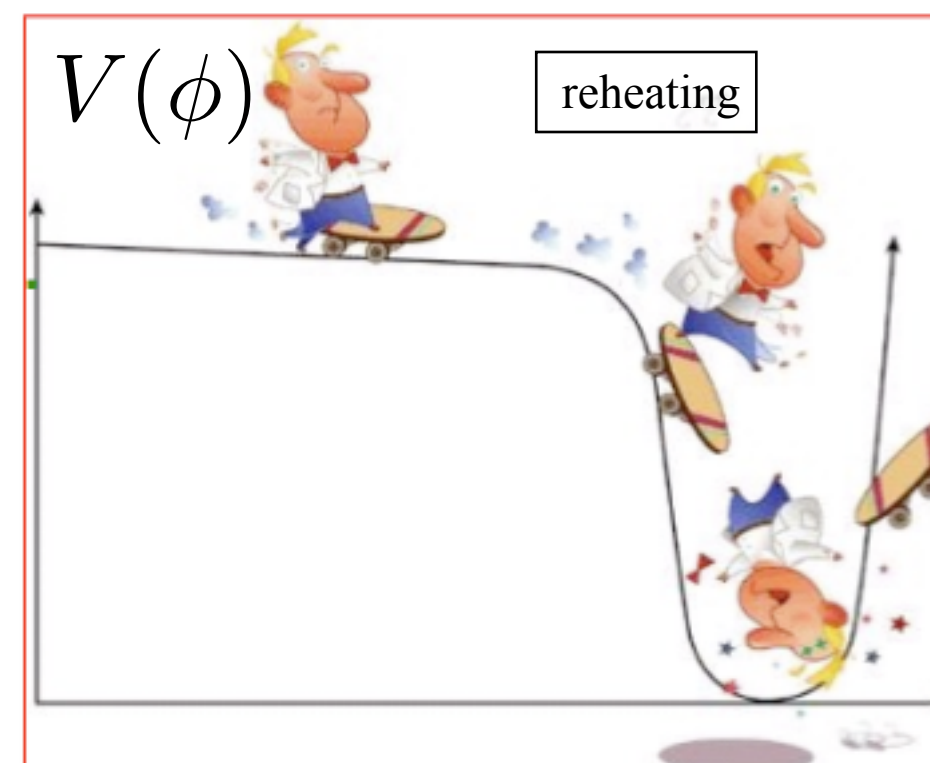
### Non-Gaussianity from Inflation

$f_{NL} \sim 0.05$  canonical inflation (single field, couple of derivatives)  
(Maldacena 2003, Acquaviva et al 2003)

$f_{NL} \sim 0.1--100$  higher order derivatives  
DBI inflation (Alishahiha, Silverstein and Tong 2004)  
UV cutoff (Craminelli and Cosmol, 2003)

$f_{NL} > 10$  curvaton models (Lyth, Ungarelli and Wands, 2003)

$f_{NL} \sim 100$  ghost inflation (Arkani-Hamed et al., Cosmol, 2004)

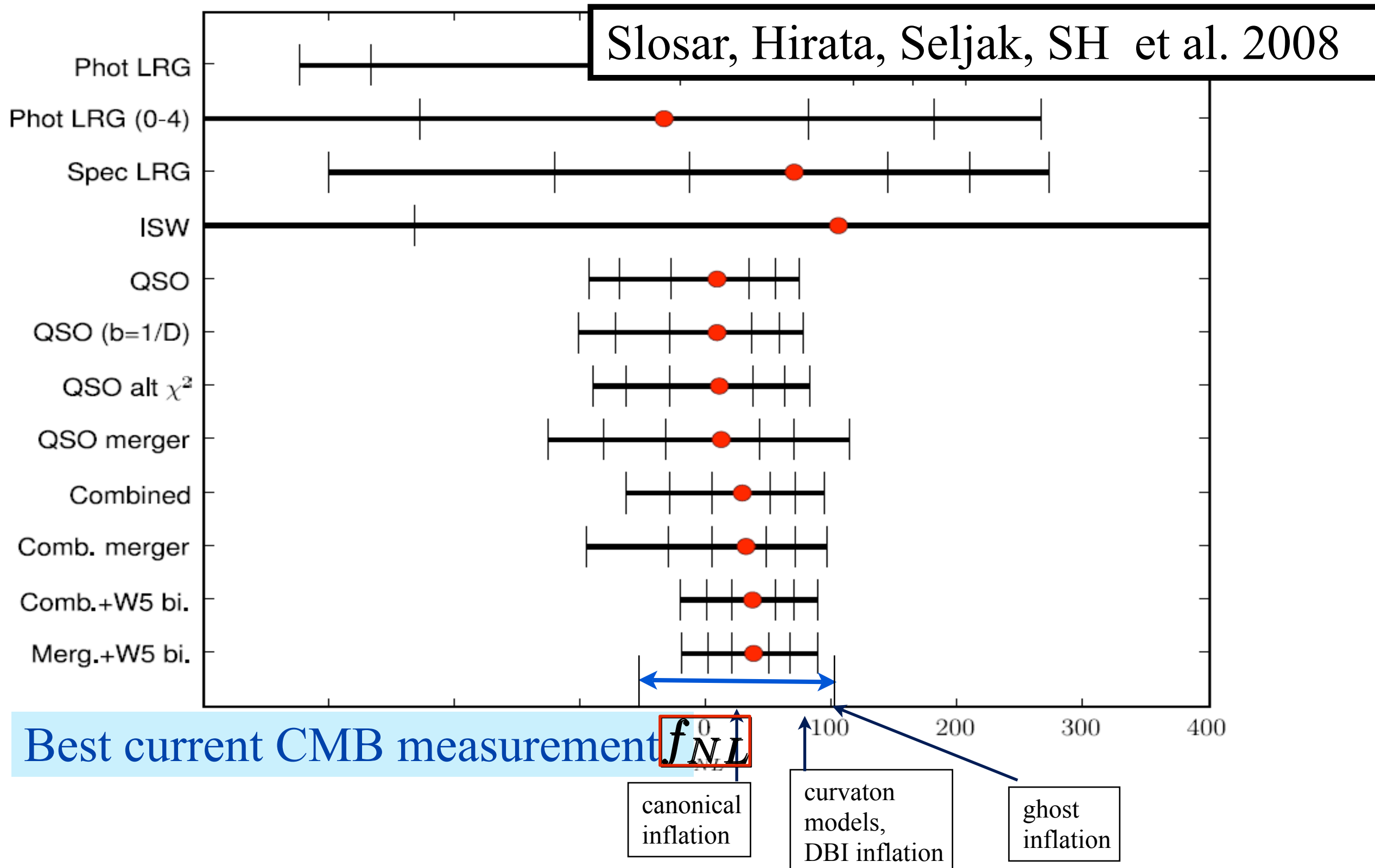


← Inflation →



# Lyman Alpha Forest: what can it do?

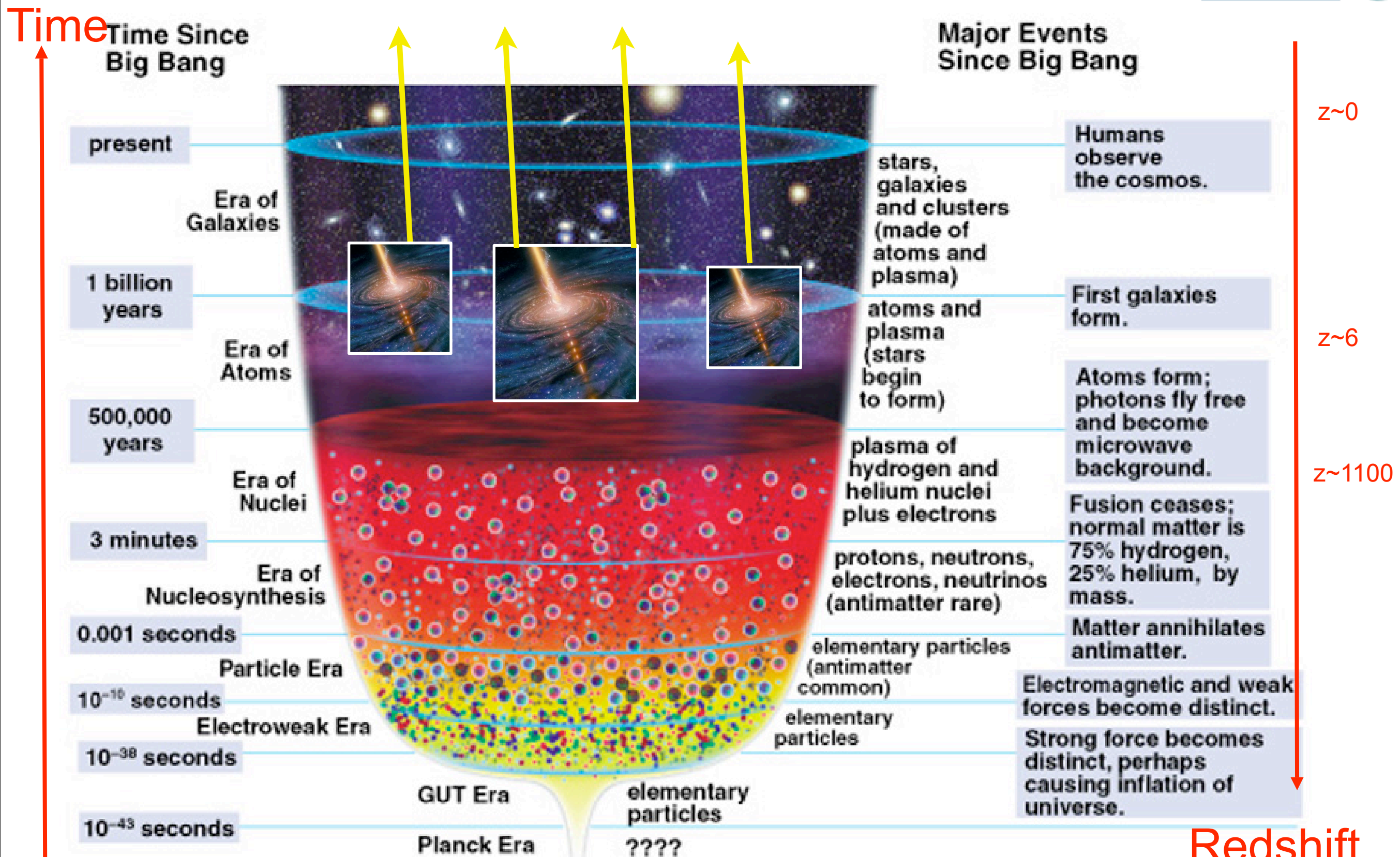
## —Non-gaussianities in Early Universe



- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations**
    - Dark Energy
  - **Scale Dependent Bias**
    - Primordial Non-gaussianities ( $f_{\text{nl}}$ )
- **Conclusion**



# Lyman Alpha Forest: what is it?



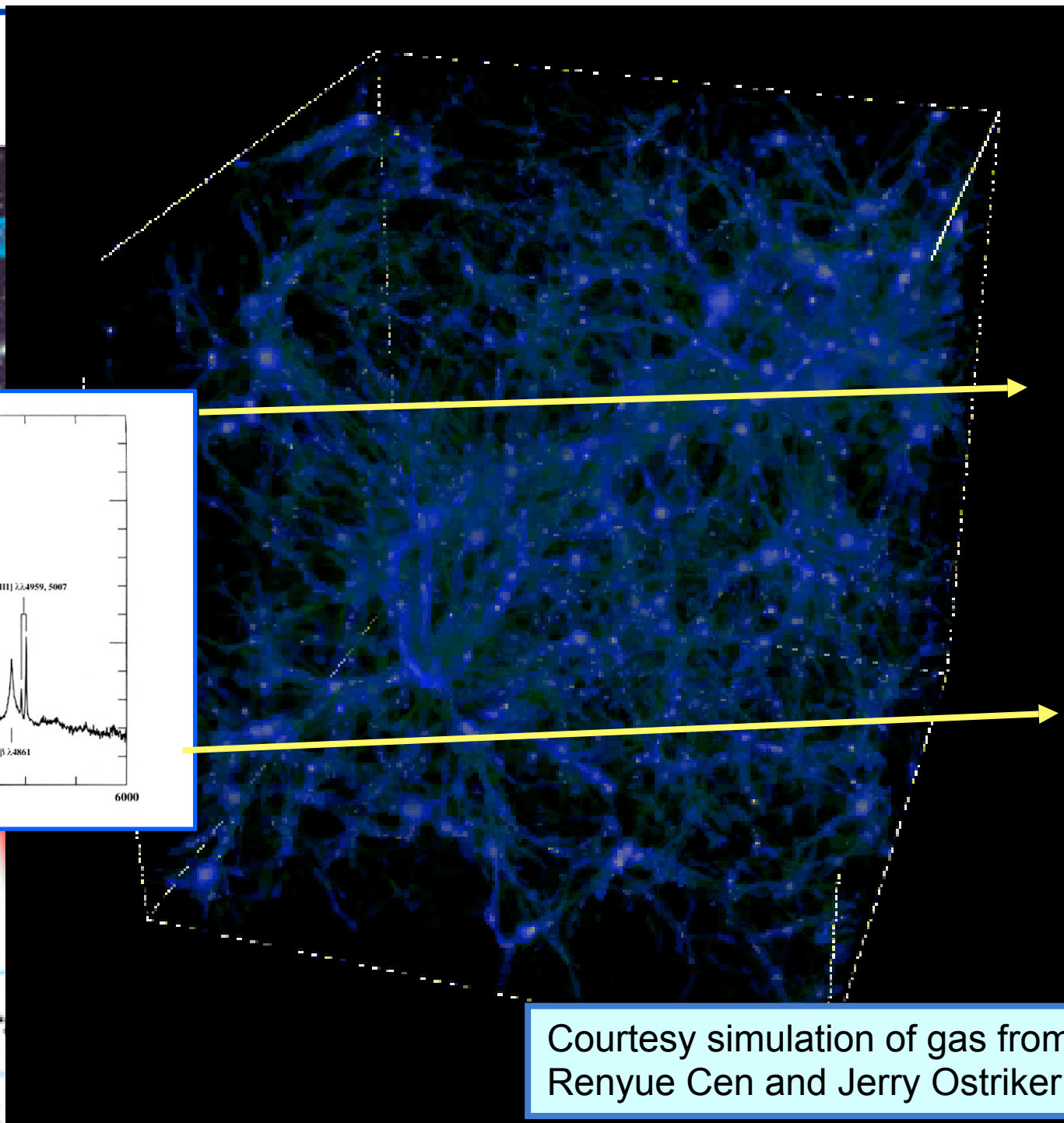
# Lyman Alpha Forest: what is it?

**Time**

Time Since Big Bang

present

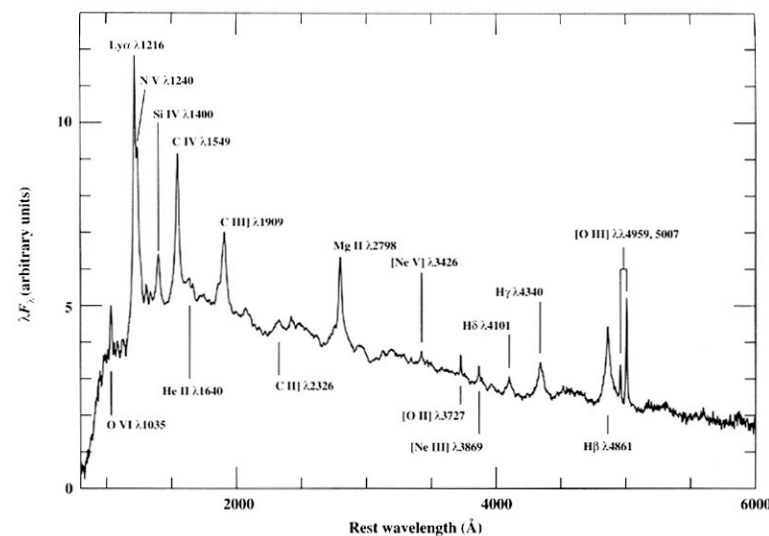
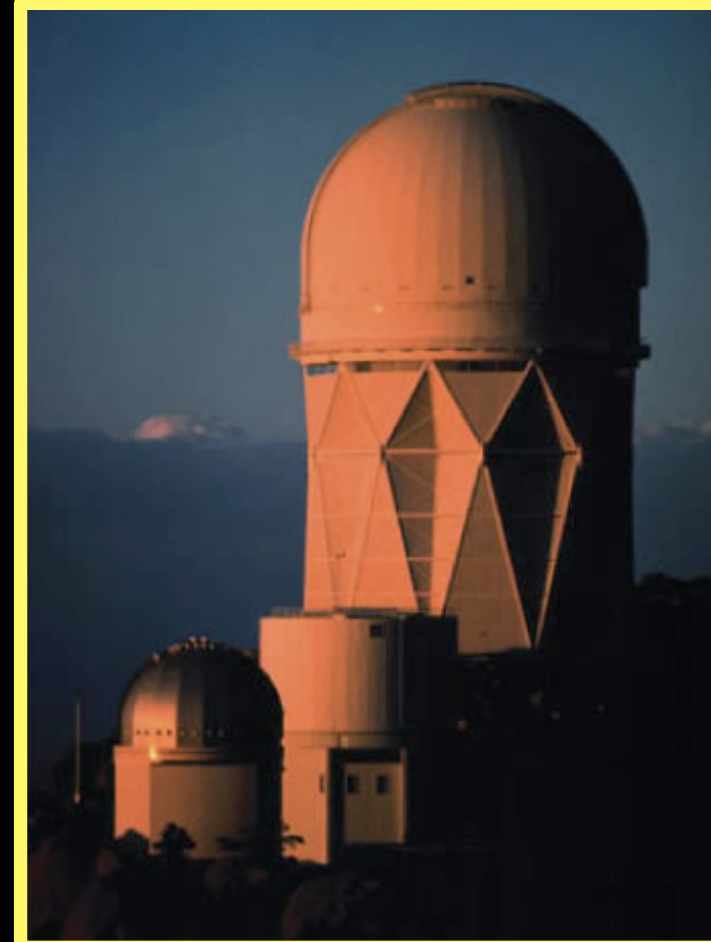
Era of Galaxies



Time Since Big Bang

z~0

Human



Courtesy simulation of gas from  
Renyue Cen and Jerry Ostriker

5 minutes

Era of Nucleosynthesis

0.001 seconds

Particle Era

$10^{-10}$  seconds

Electroweak

$10^{-38}$  seconds

$10^{-43}$  seconds

GUT Era

Planck Era

elementary particles

????

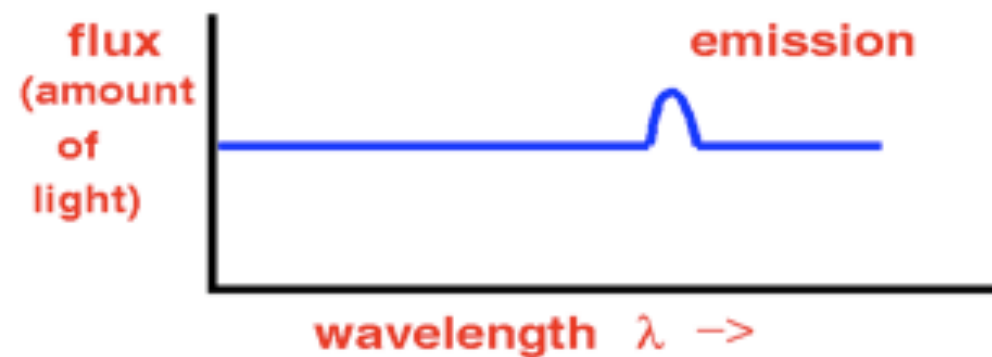
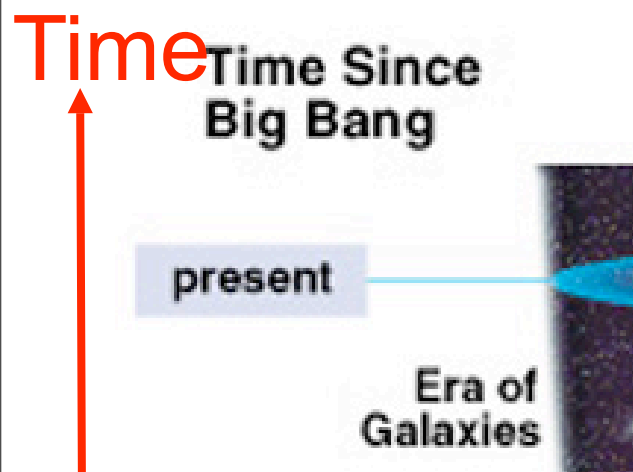
matter annihilates antimatter.

electromagnetic and weak forces become distinct.

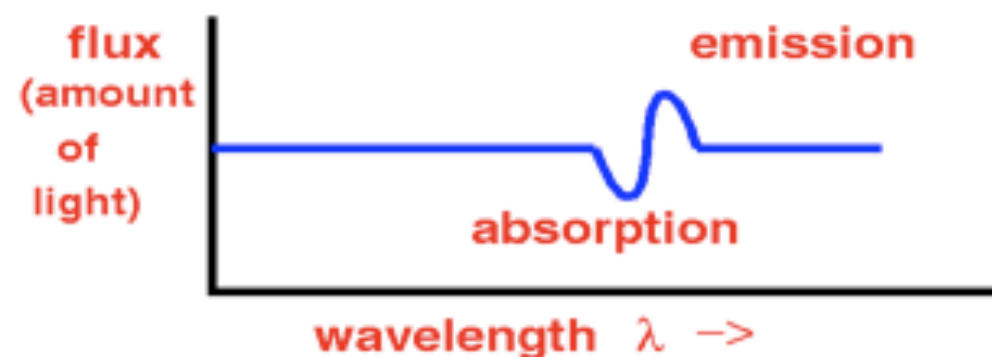
Strong force becomes distinct, perhaps causing inflation of universe.

Redshift

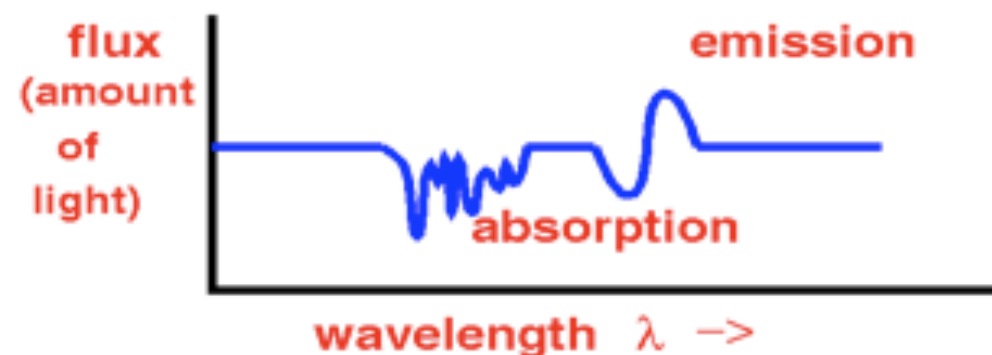
# Lyman Alpha Forest: what is it?



One absorbing cloud close by

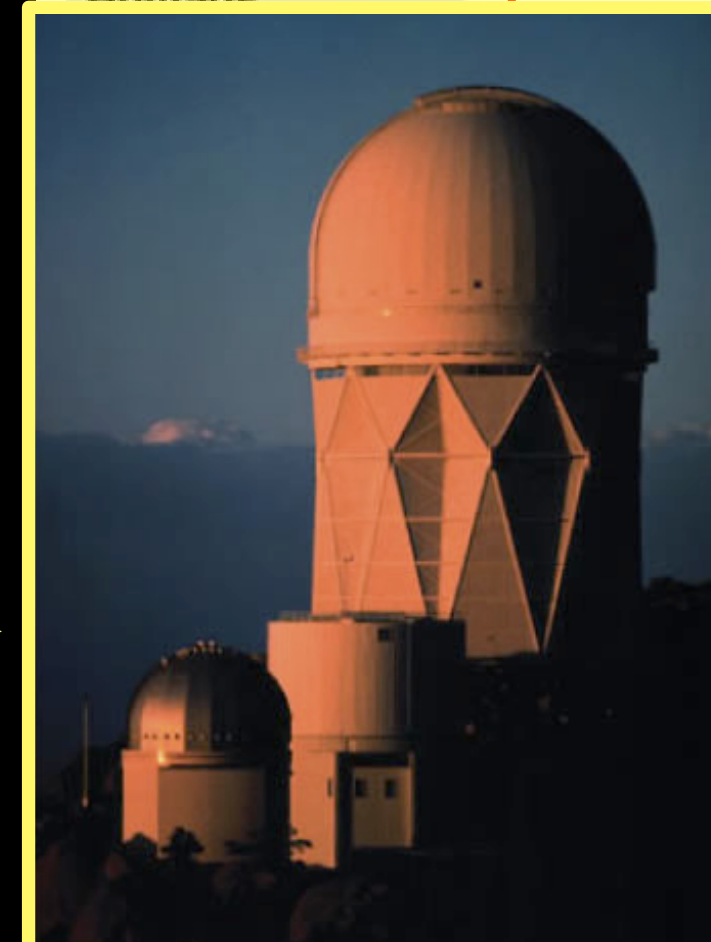


Several absorbing clouds



Time Since Big Bang

$z \sim 0$



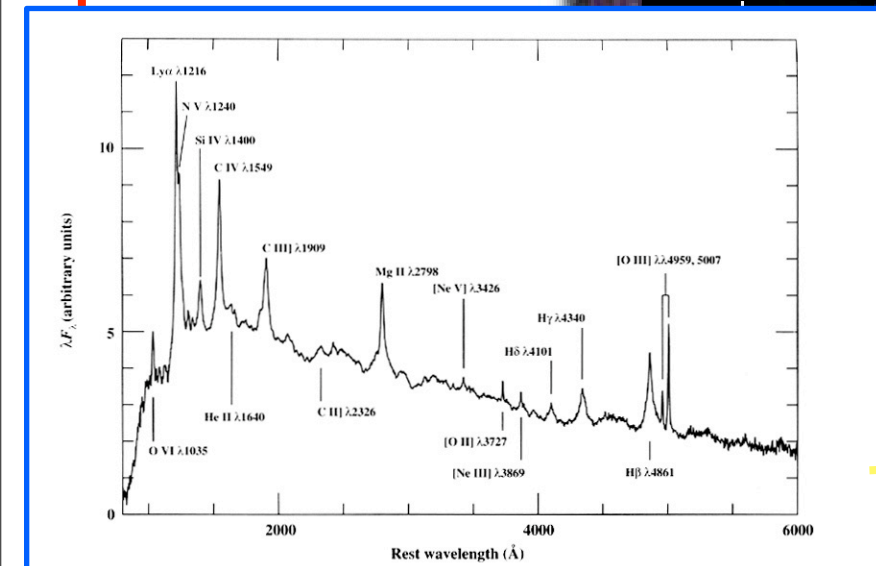
matter annihilates antimatter.

electromagnetic and weak forces become distinct.

strong force becomes distinct, perhaps causing inflation of

Courtesy image from Joanne Cohn's website

Redshift



5 minutes

Era of Nucleosynthesis

0.001 seconds

Particle Era

$10^{-10}$  seconds

Electroweak

$10^{-38}$  seconds

$10^{-43}$  seconds

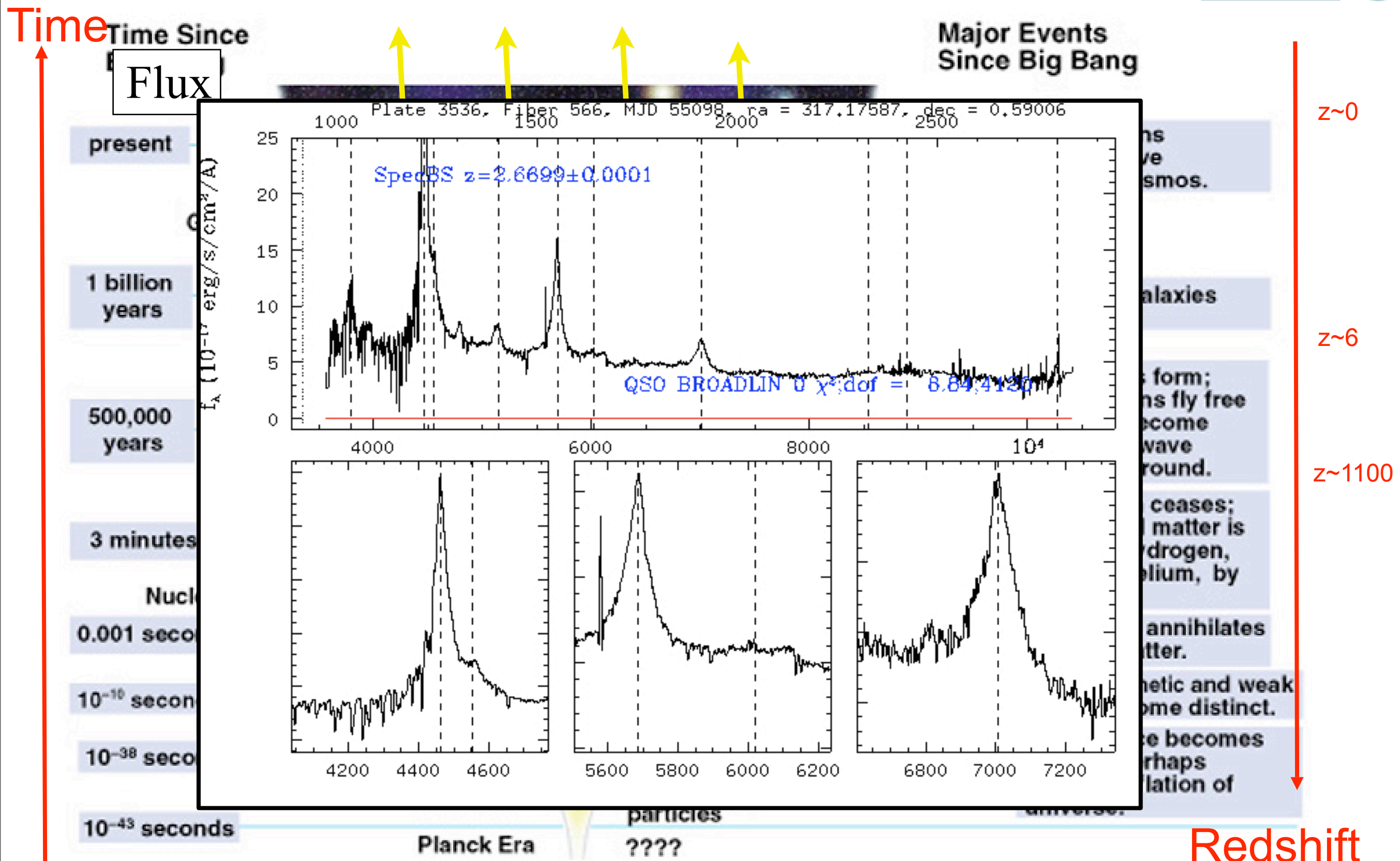
GUT Era

elementary particles

Planck Era

????

# Lyman Alpha Forest: what is it?





# Lyman Alpha Forest: what is it?

Time

Locates the Neutral Hydrogen, thus overdensities of the Universe.

Time Since Big Bang

Flux

present

1 billion years

500,000 years

3 minutes

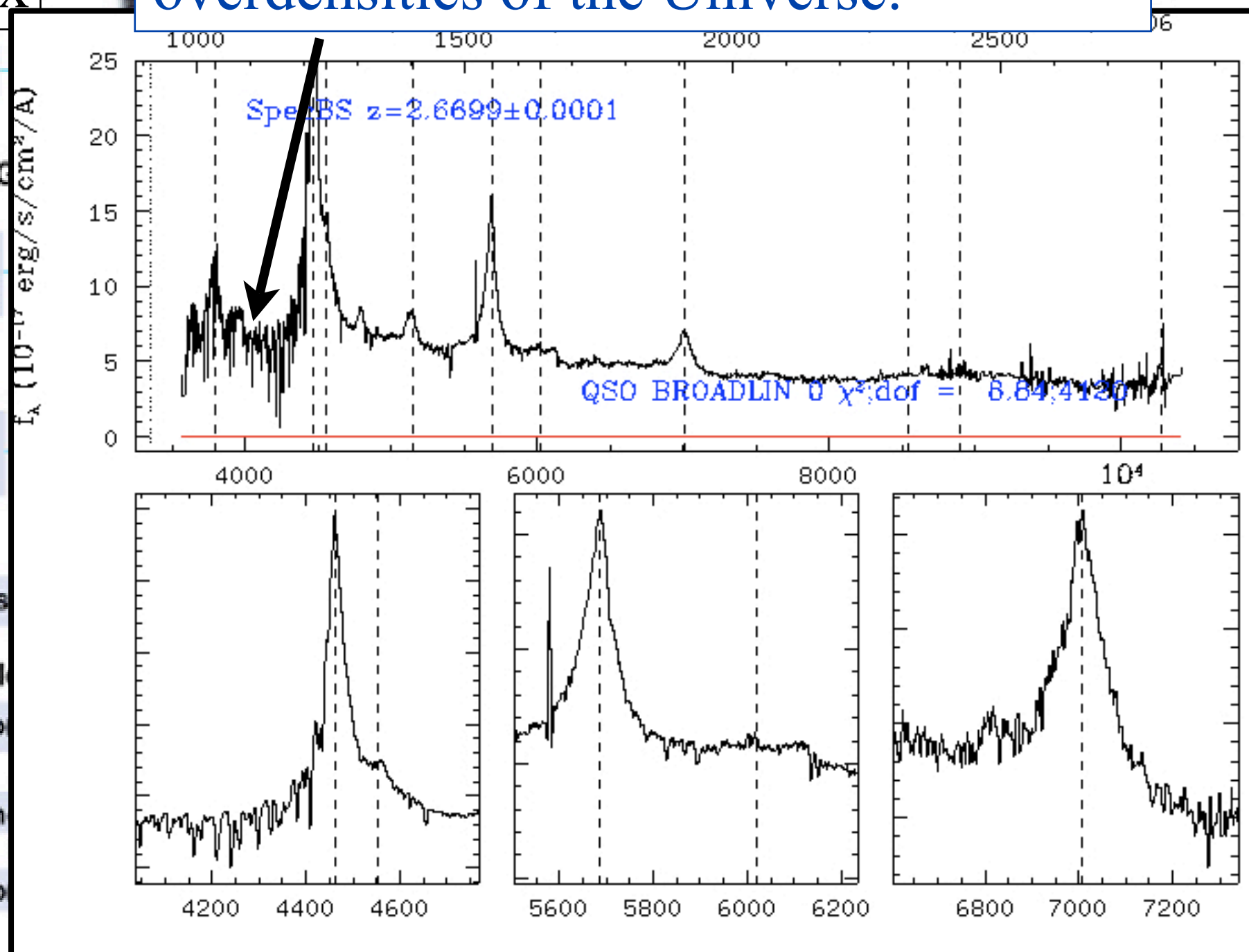
Nucleosynthesis

0.001 seconds

$10^{-10}$  seconds

$10^{-38}$  seconds

$10^{-43}$  seconds



$z \sim 0$

$z \sim 6$

$z \sim 1100$

Redshift

Planck Era

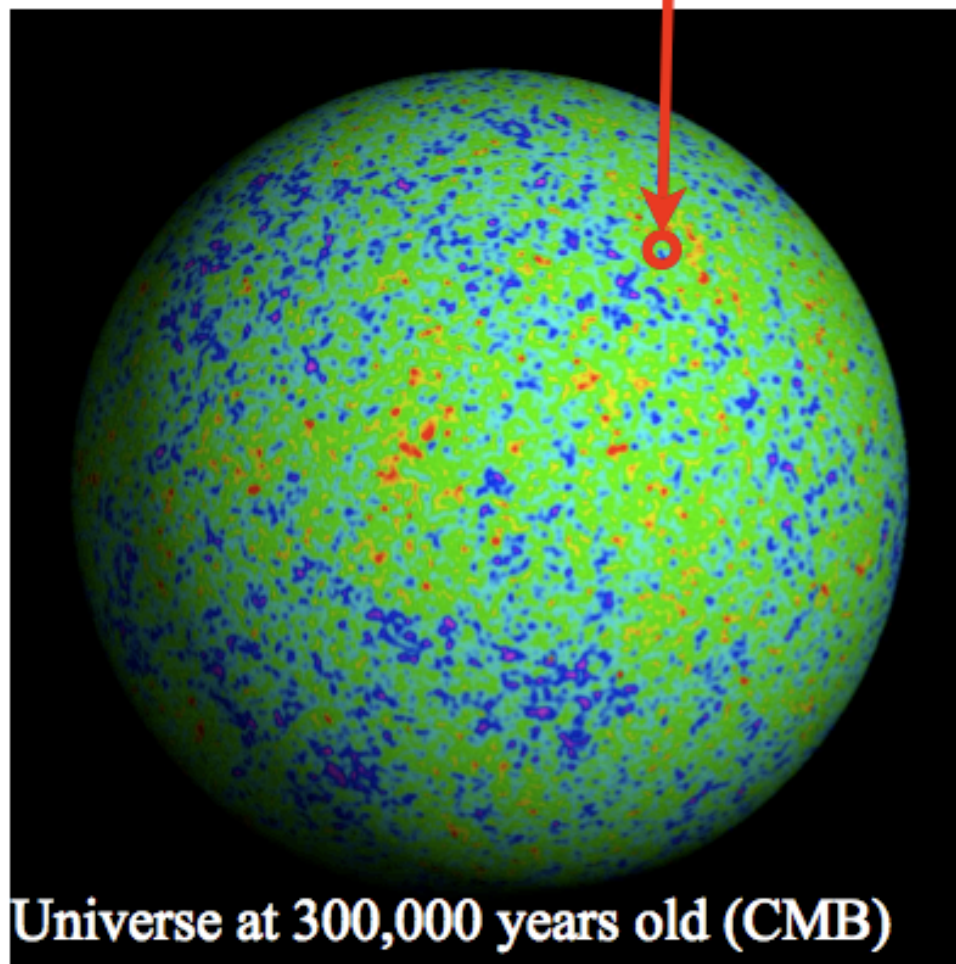
particles  
????

- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations**
    - **Dark Energy**
  - **Scale Dependent Bias**
    - **Primordial Non-gaussianities ( $f_{\text{nl}}$ )**
- **Conclusion**

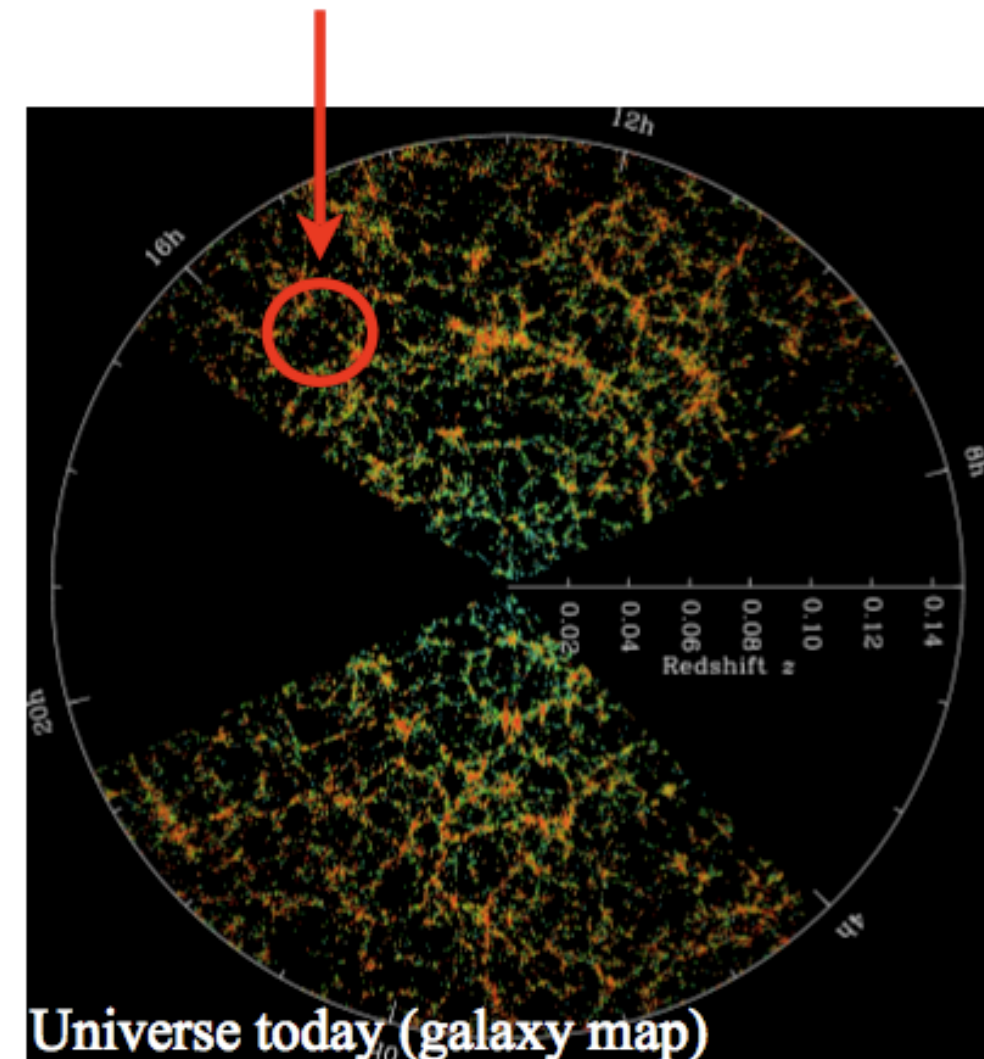
# Lyman Alpha Forest: what can it do?

What are baryon acoustic oscillations (BAO)?

These fluctuations of 1 part in  $10^5$   
gravitationally grow into...



...these ~unity fluctuations today



This sound wave can be used as a “standard ruler”  
Dark energy changes this apparent ruler size

Courtesy slide from David Schlegel

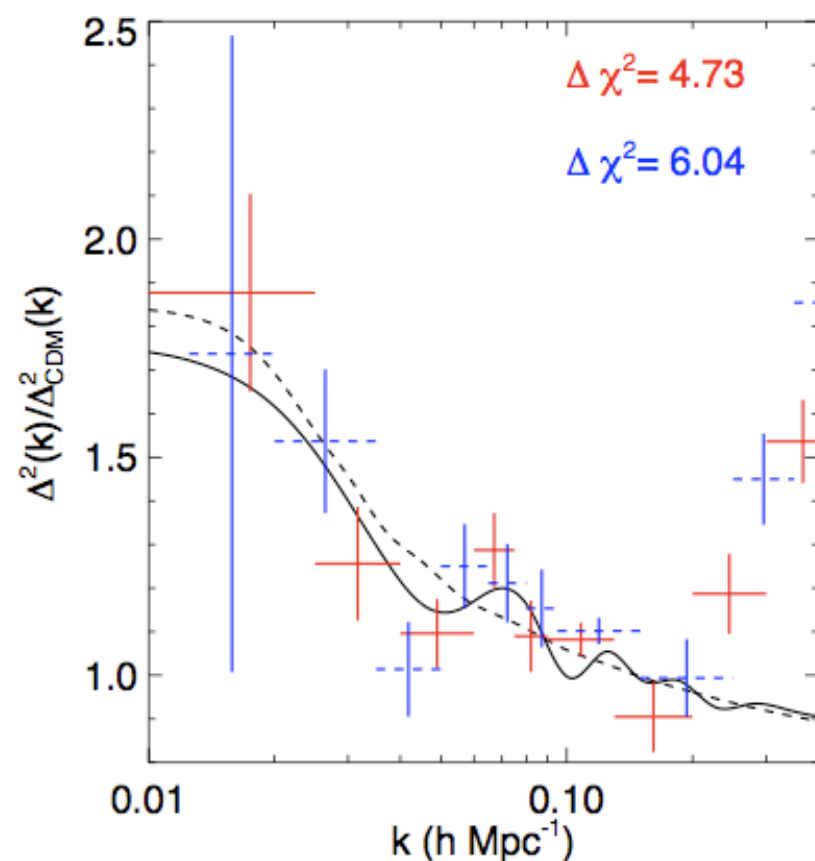
# Lyman Alpha Forest: what can it do?

What are baryon acoustic oscillations (BAO)?

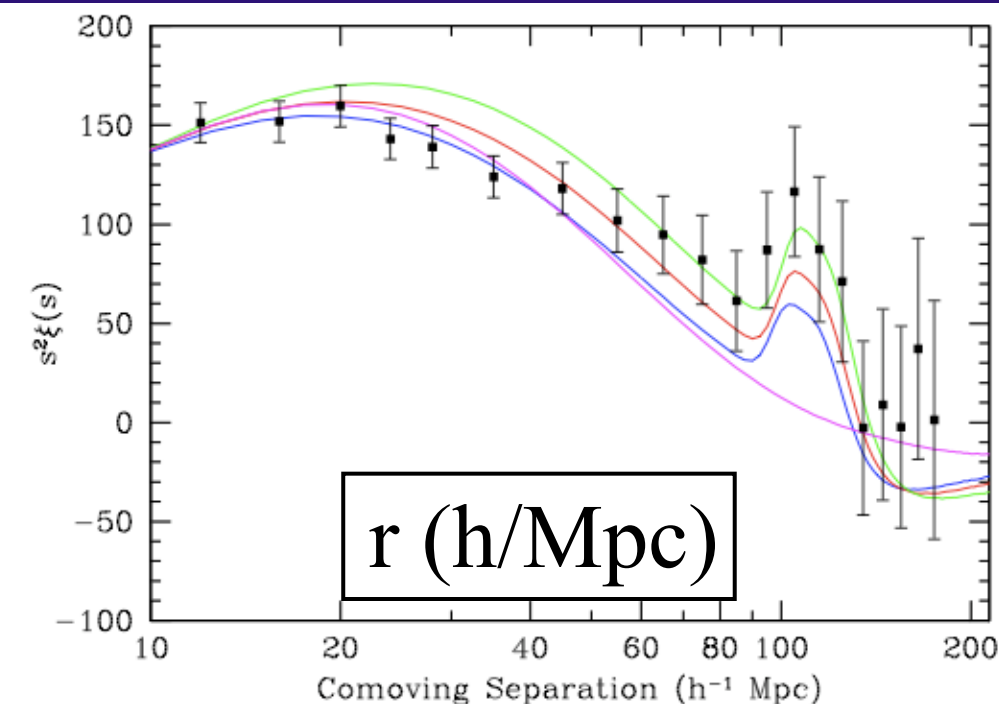
$$r^2 \xi(r)$$

These fluctuations of 1 part in  $10^5$  gravitationally grow into...

...these ~



Padmanabhan et al. 2006



Eisenstein et al. 2005

Universe today (galaxy map)

ed as a “standard ruler”

apparent ruler size

Courtesy slide from David Schlegel



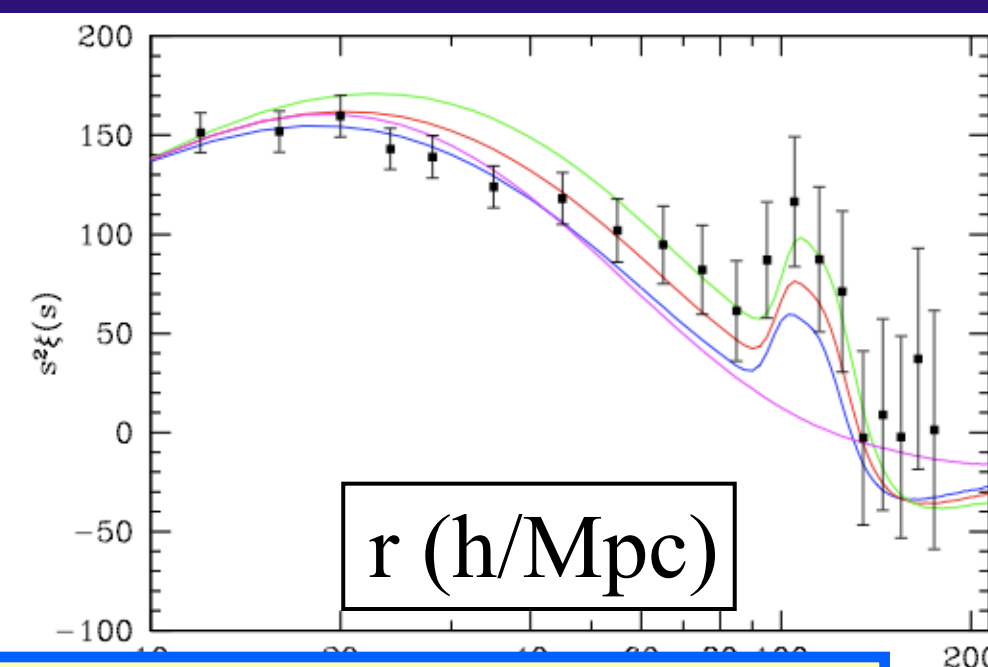
# Lyman Alpha Forest: what can it do?

What are baryon acoustic oscillations (BAO)?

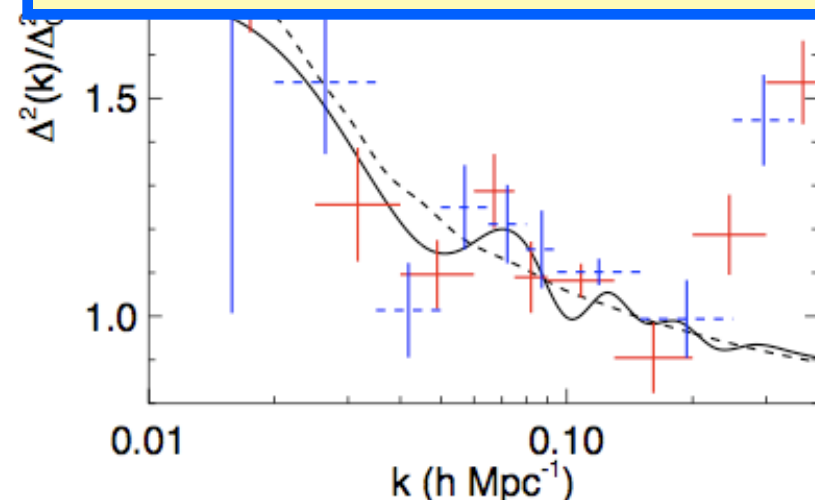
$$r^2 \xi(r)$$

These fluctuations of 1 part in  $10^5$  gravitationally grow into...

...these ~



What happens if we use Lyman-alpha forest ?



Padmanabhan et al. 2006

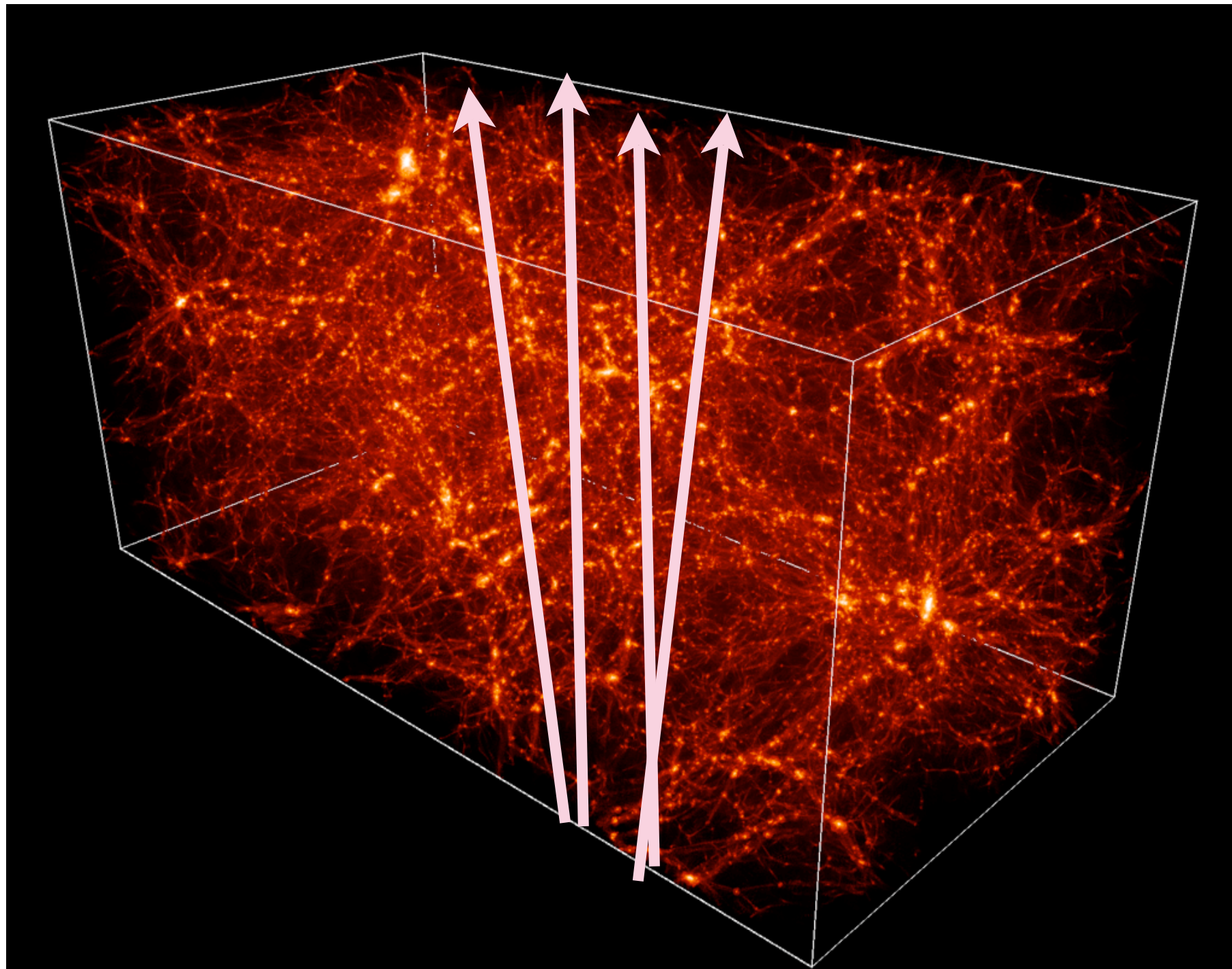
Universe today (galaxy map)

ed as a "standard ruler"

apparent ruler size

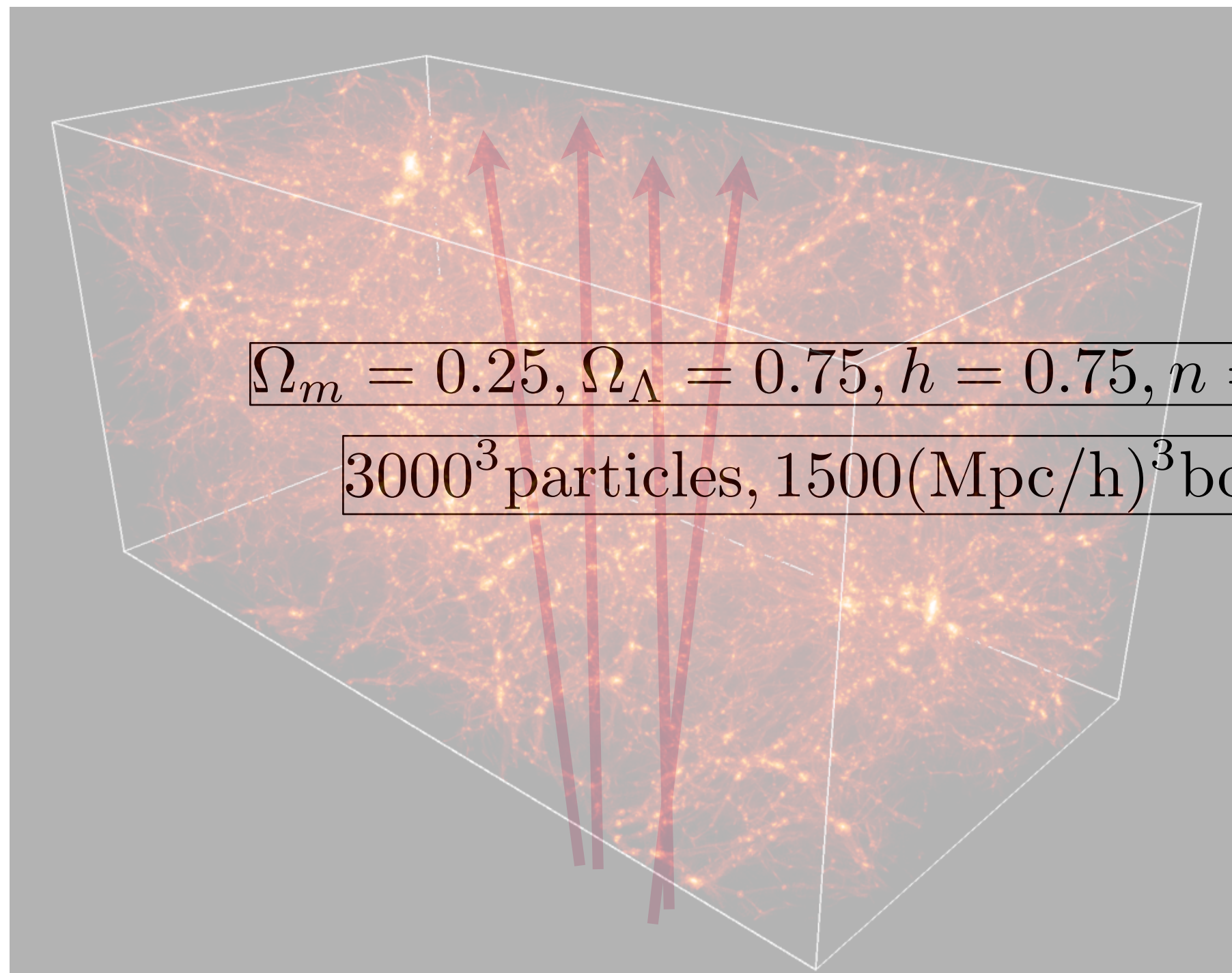
Courtesy slide from David Schlegel

# Lyman Alpha Forest: what can it do?





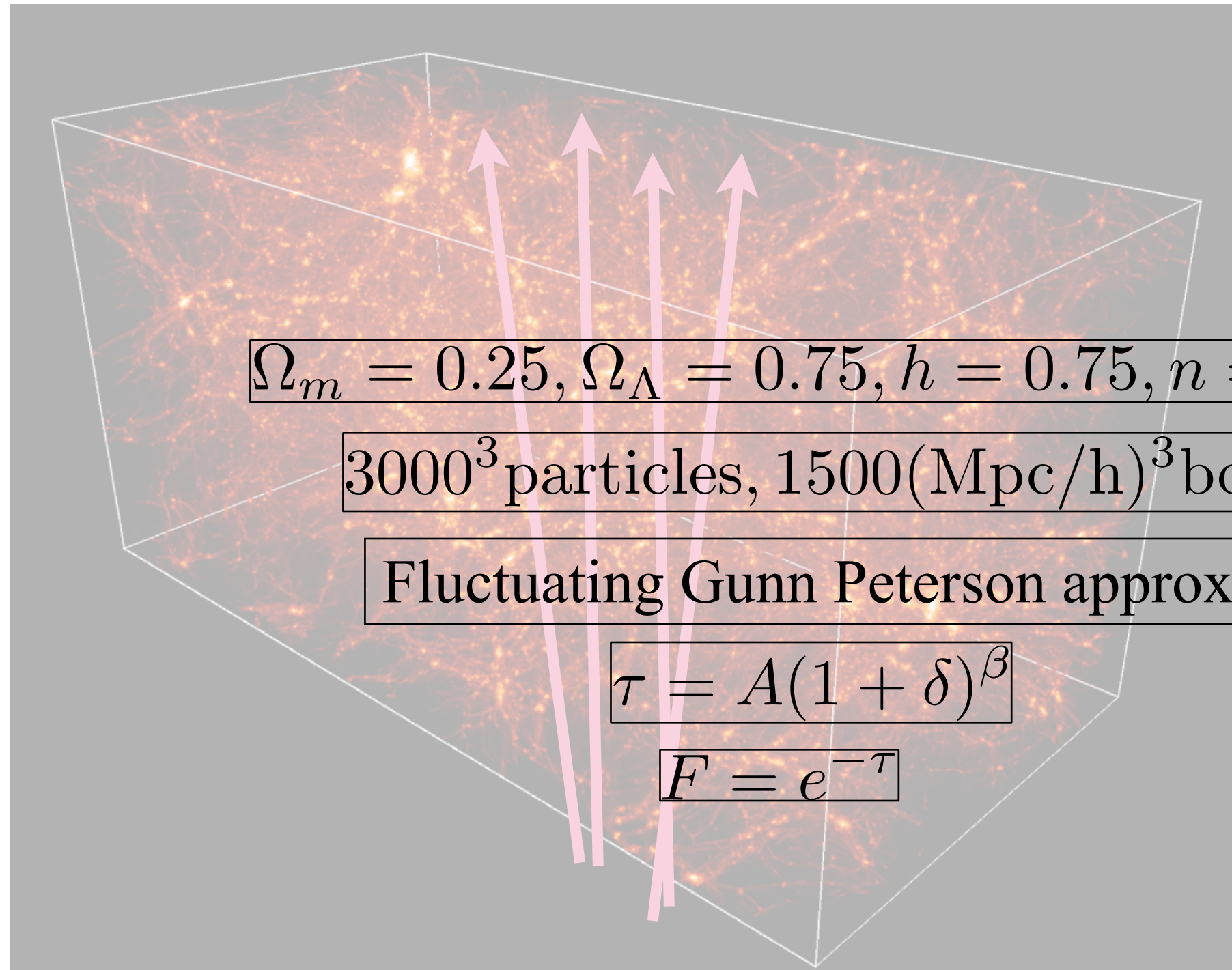
# Lyman Alpha Forest: what can it do?



$$\Omega_m = 0.25, \Omega_\Lambda = 0.75, h = 0.75, n = 0.97, \sigma_8 = 0.8$$

$3000^3$  particles,  $1500(\text{Mpc}/h)^3$  box,  $3000^3$  grid

# Lyman Alpha Forest: what can it do?



$$\Omega_m = 0.25, \Omega_\Lambda = 0.75, h = 0.75, n = 0.97, \sigma_8 = 0.8$$

$$3000^3 \text{ particles, } 1500(\text{Mpc}/h)^3 \text{ box, } 3000^3 \text{ grid}$$

Fluctuating Gunn Peterson approximation

$$\tau = A(1 + \delta)^\beta$$

$$F = e^{-\tau}$$



# Lyman Alpha Forest: what can it do?

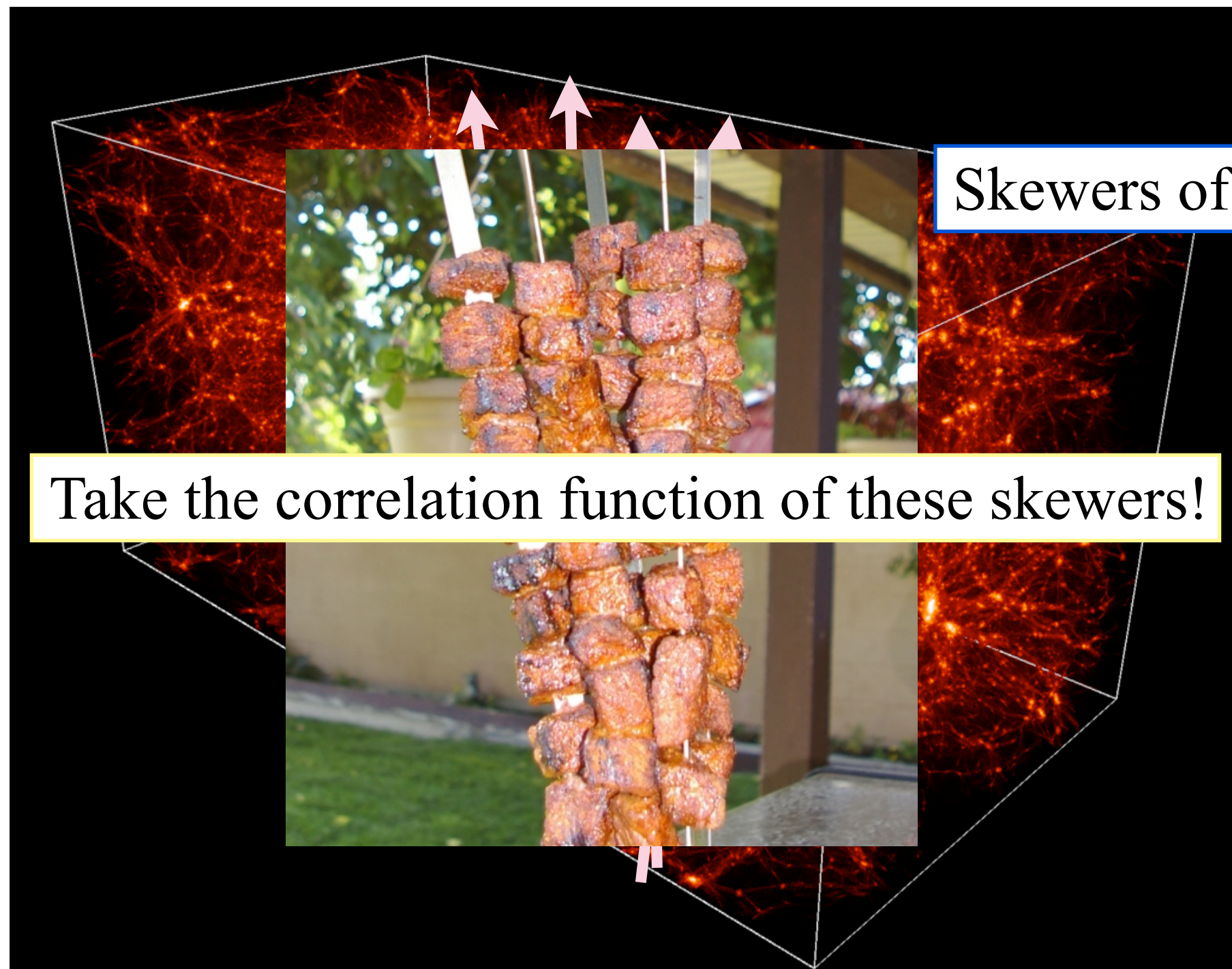
- **Dark Energy via Baryon Acoustic Oscillations**



Skewers of Neutral Hydrogen

# Lyman Alpha Forest: what can it do?

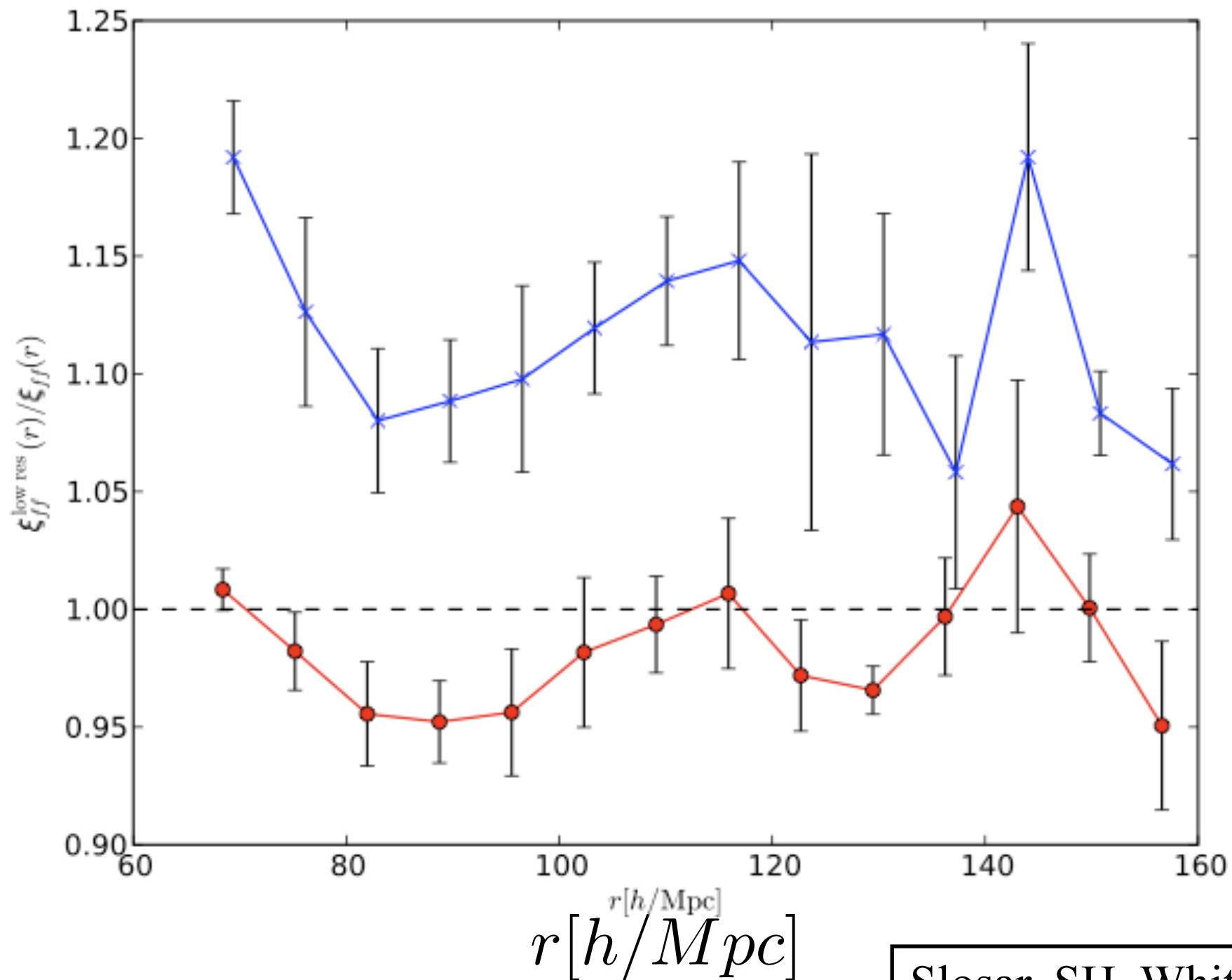
- **Dark Energy via Baryon Acoustic Oscillations**





# How about the resolution effect?

$$\xi_{ff}^{\text{low res}}(r) / \xi_{ff}(r)$$



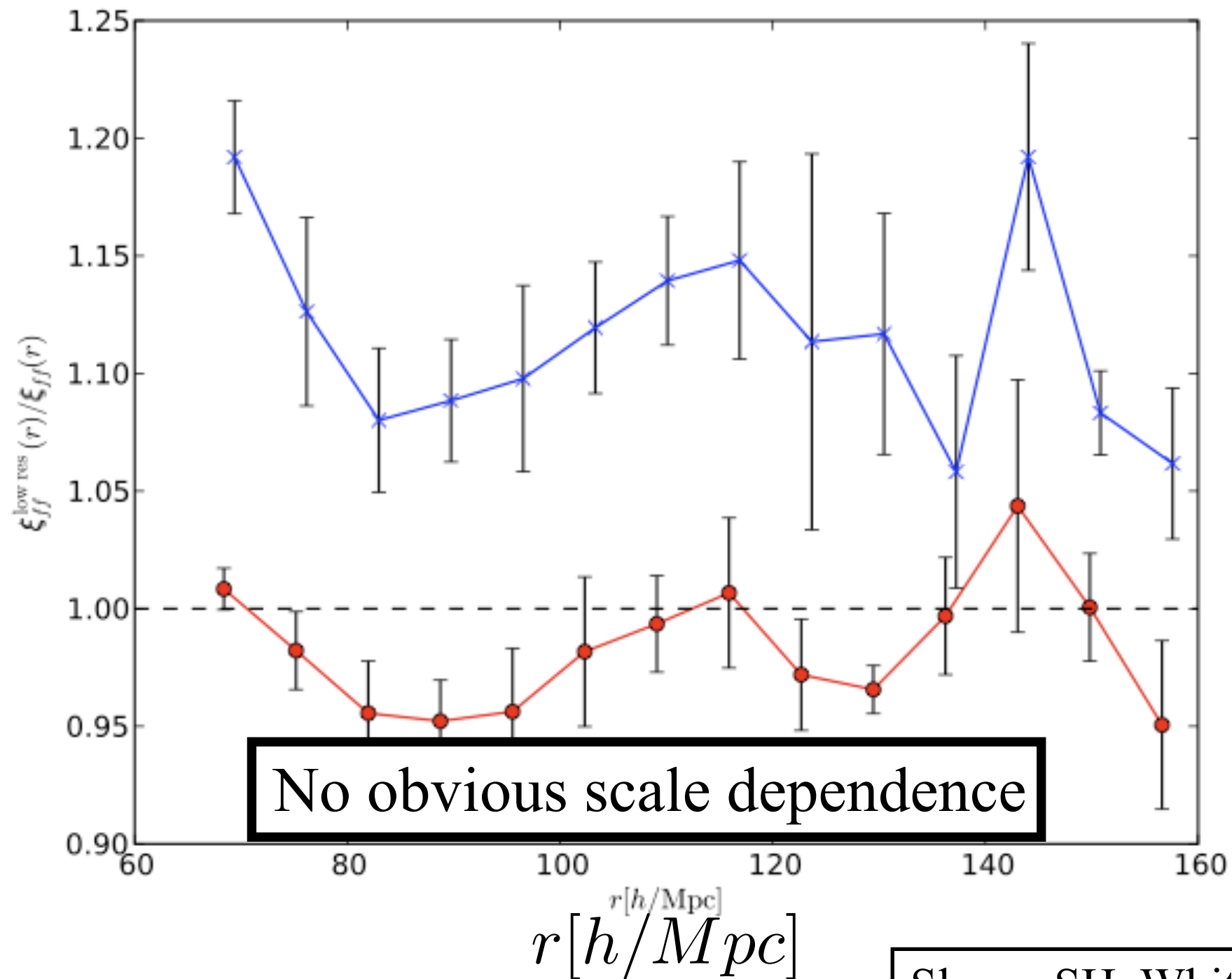
resolution 4X worse

resolution 2X worse

Slosar, SH, White & Louis (2009)

# How about the resolution effect?

$$\xi_{ff}^{\text{low res}}(r)/\xi_{ff}(r)$$



resolution 4X worse

resolution 2X worse

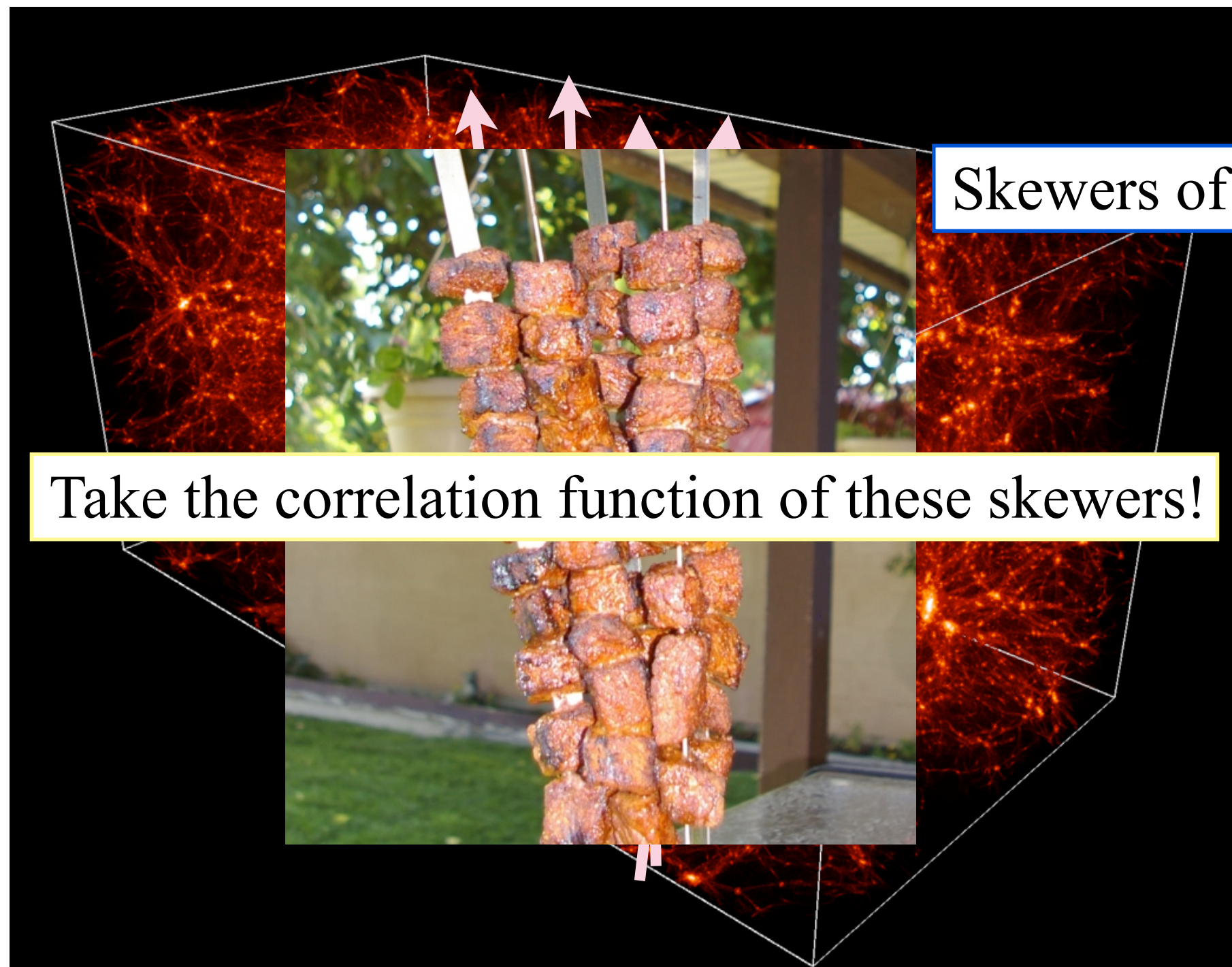
No obvious scale dependence

Slosar, SH, White & Louis (2009)



# Lyman Alpha Forest: what can it do?

- **Dark Energy via Baryon Acoustic Oscillations**



# Lyman Alpha Forest: what can it do?



- **Dark Energy via Baryon Acoustic Oscillations**

—the correlation function:

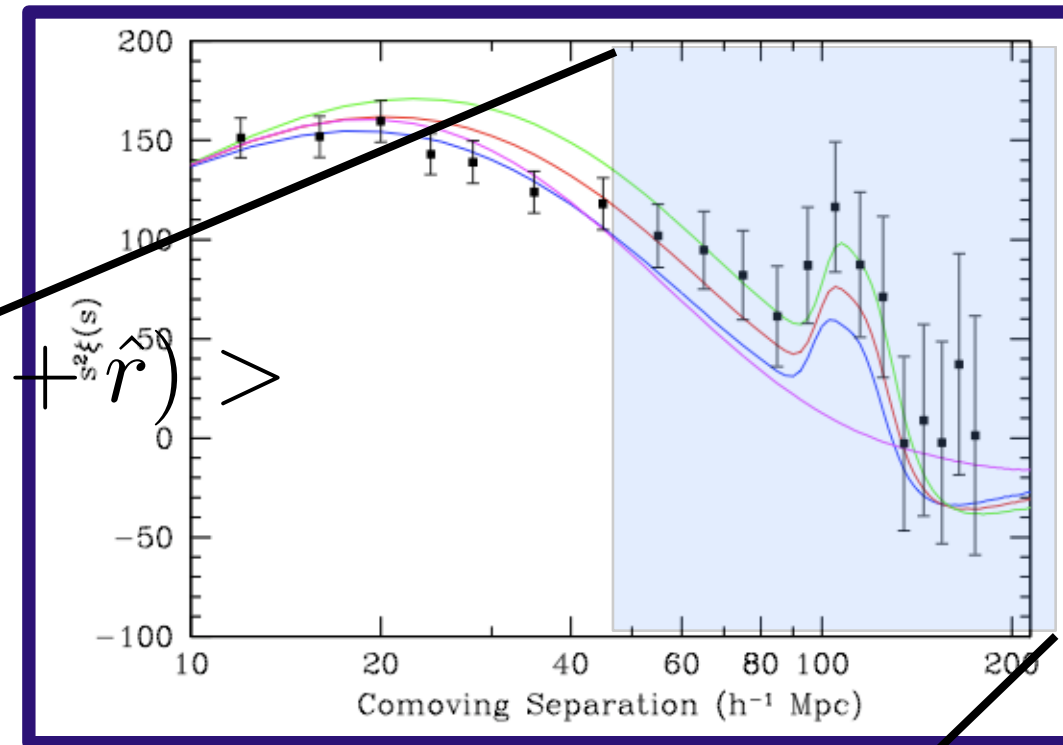
$$\xi_f(r) = \langle \delta_f(\hat{x}) \delta_f(\hat{x} + \hat{r}) \rangle$$

# Lyman Alpha Forest: what can it do?

- Dark Energy via Baryon Acoustic Oscillations

—the correlation function:

$$\xi_f(r) = \langle \delta_f(\hat{x}) \delta_f(\hat{x} + \hat{r}) \rangle$$

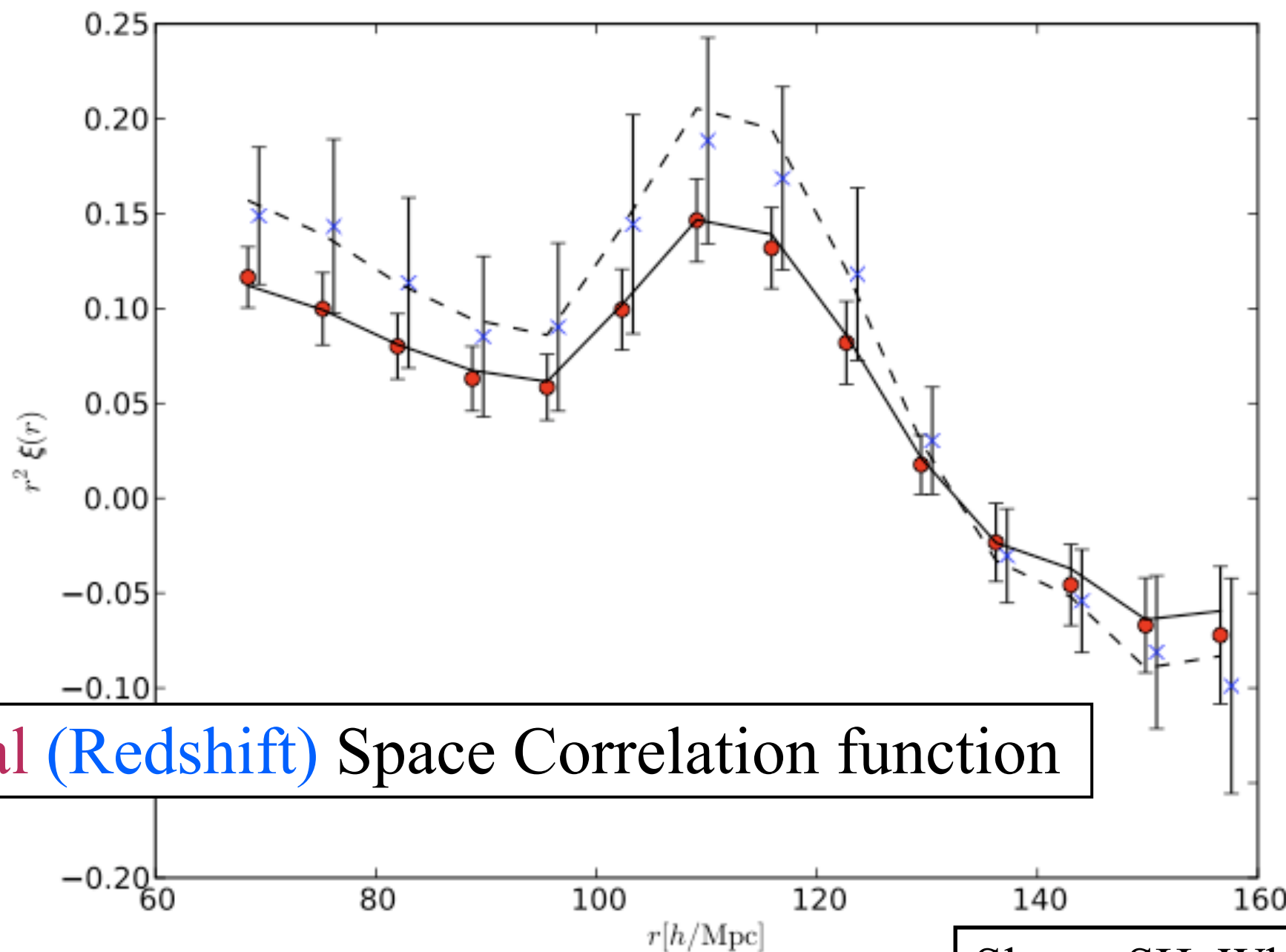


# Lyman Alpha Forest: what can it do?

- Dark Energy via Baryon Acoustic Oscillations

← take the correlation function:

$$r^2 \xi(r)$$



Flux Real (Redshift) Space Correlation function

Slosar, SH, White & Louis (2009)

$r$  (h/Mpc)

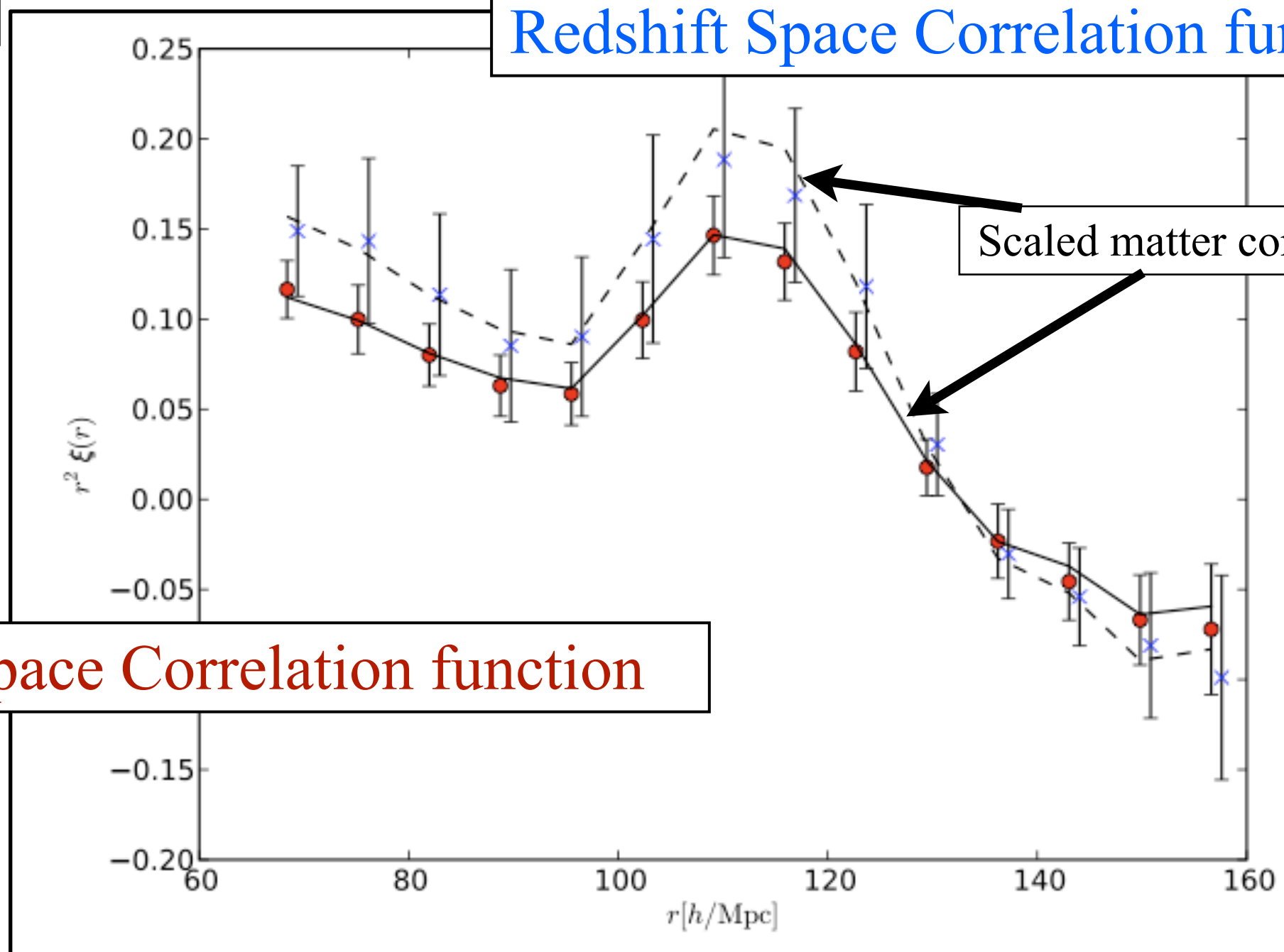
# Lyman Alpha Forest: what can it do?

$$r^2 \xi(r)$$

Redshift Space Correlation function

Scaled matter correlation functions

Real Space Correlation function



$r \text{ (h/Mpc)}$

Slosar, SH, White & Louis (2009)



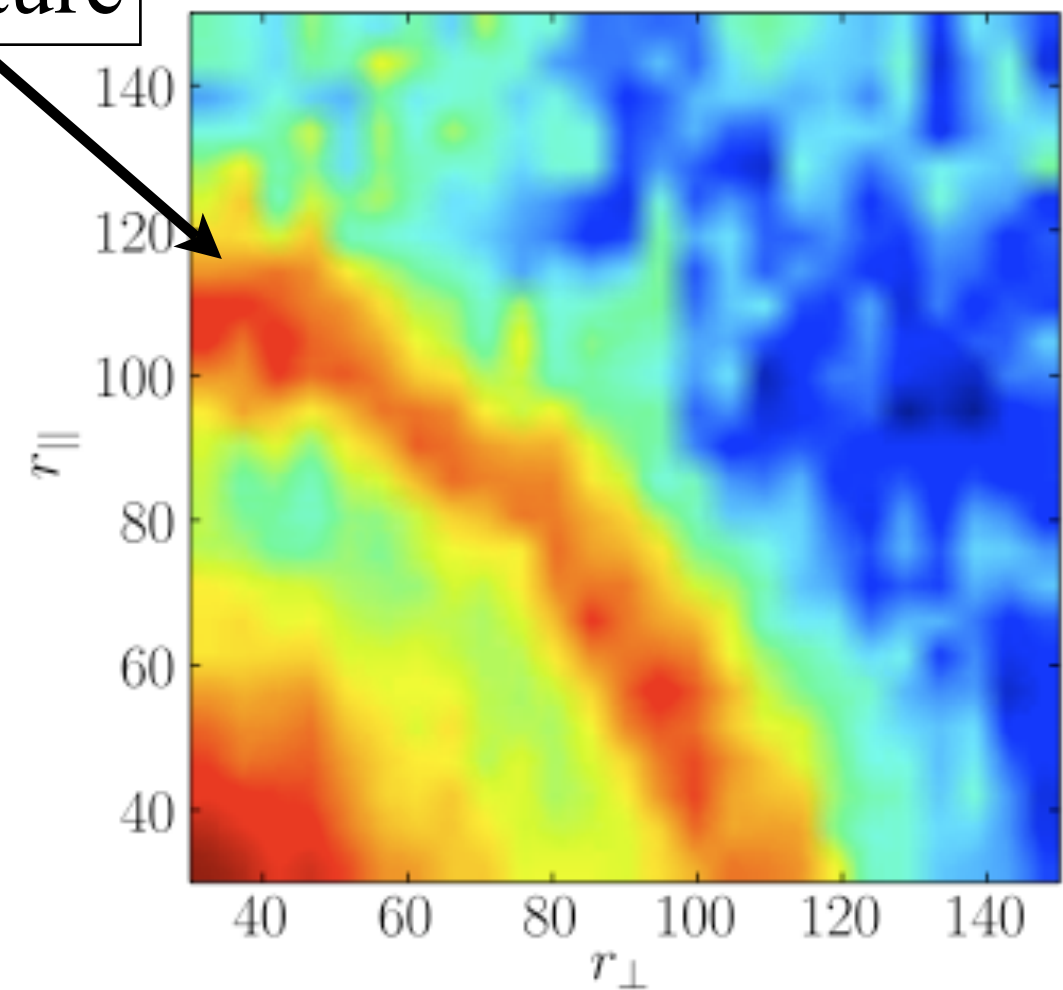
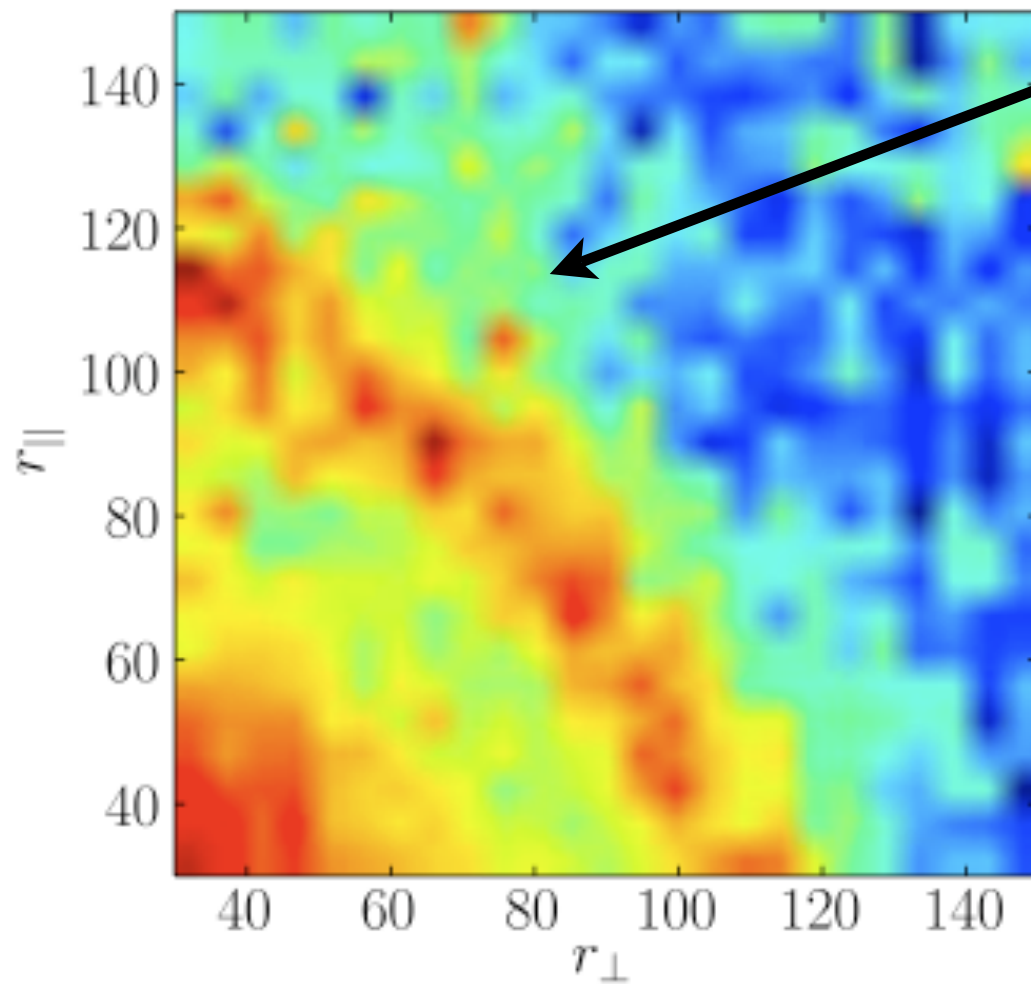
# Lyman Alpha Forest: what can it do?

Real Space Correlation function

Matter

Flux

BAO feature



Slosar, SH, White & Louis (2009)

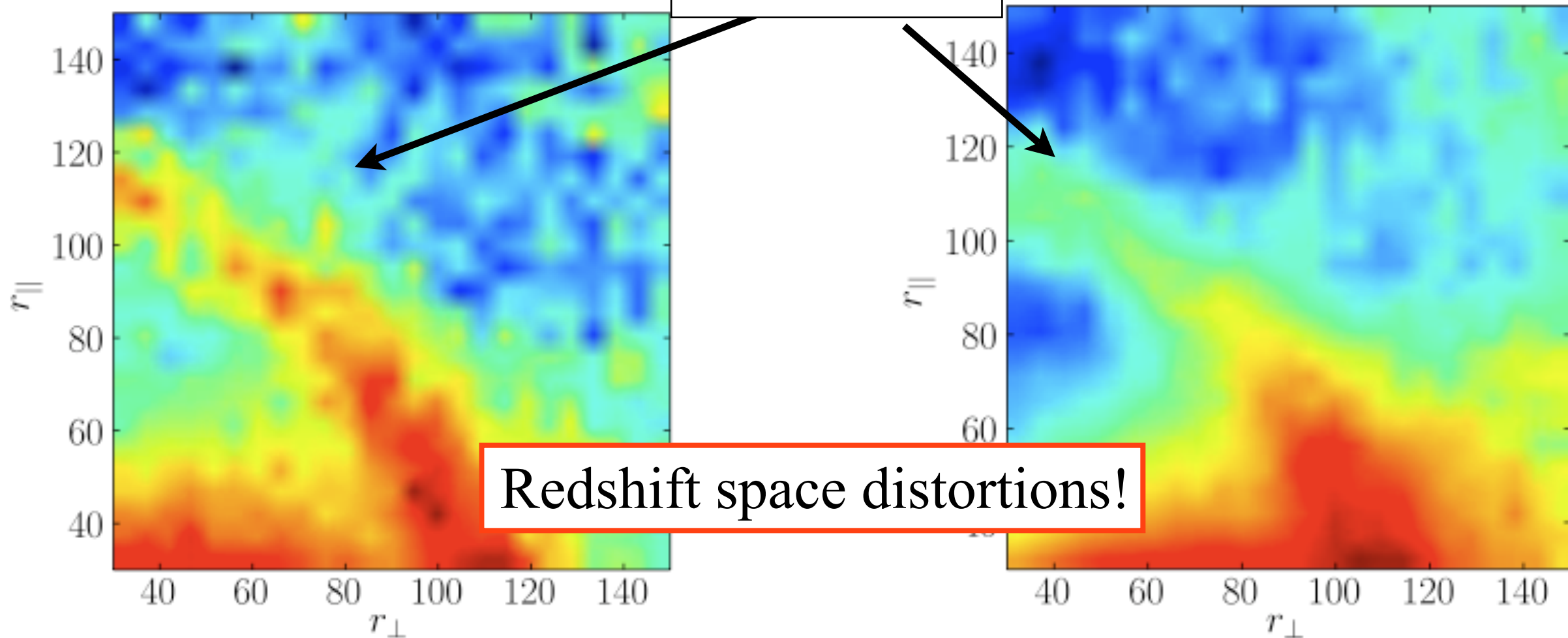
# Lyman Alpha Forest: what can it do?

Redshift Space Correlation function

Matter

Flux

BAO feature



Slosar, SH, White & Louis (2009)

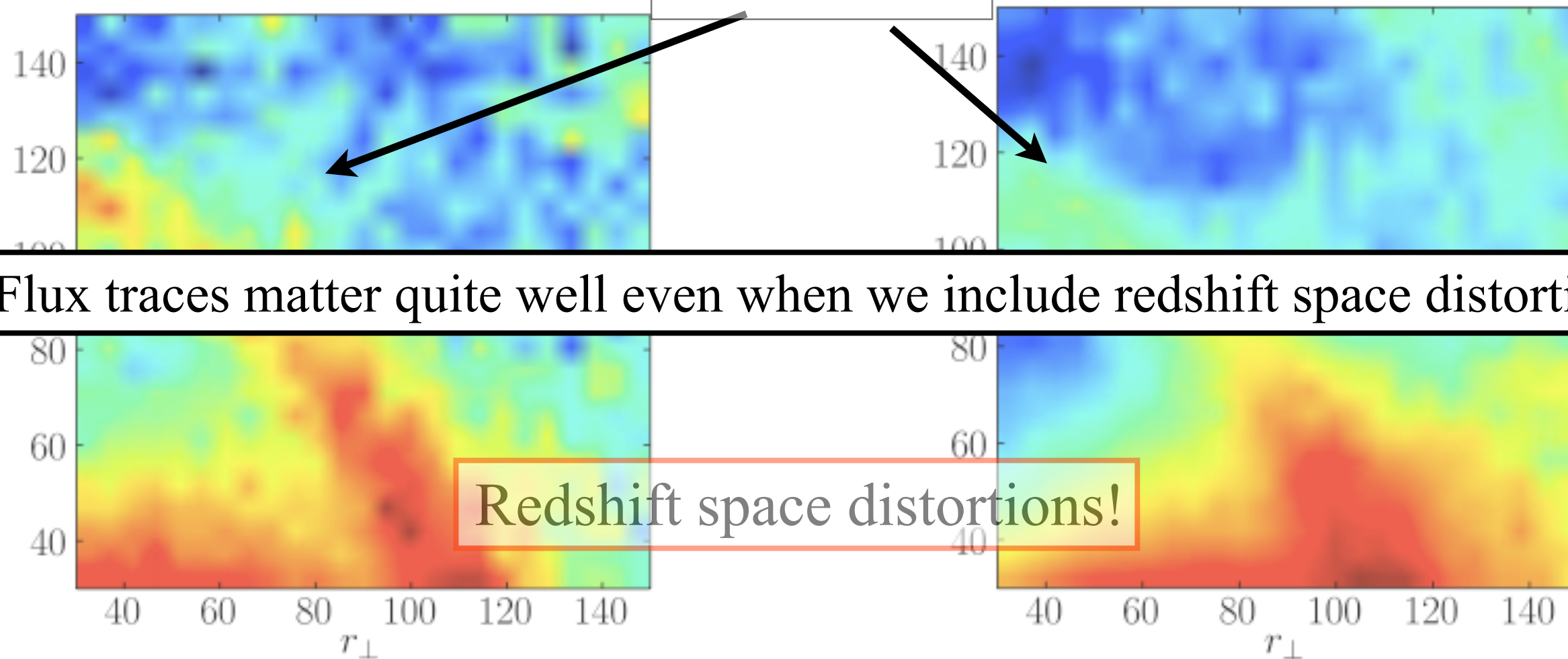
# Lyman Alpha Forest: what can it do?

Redshift Space Correlation function

Matter

Flux

BAO feature

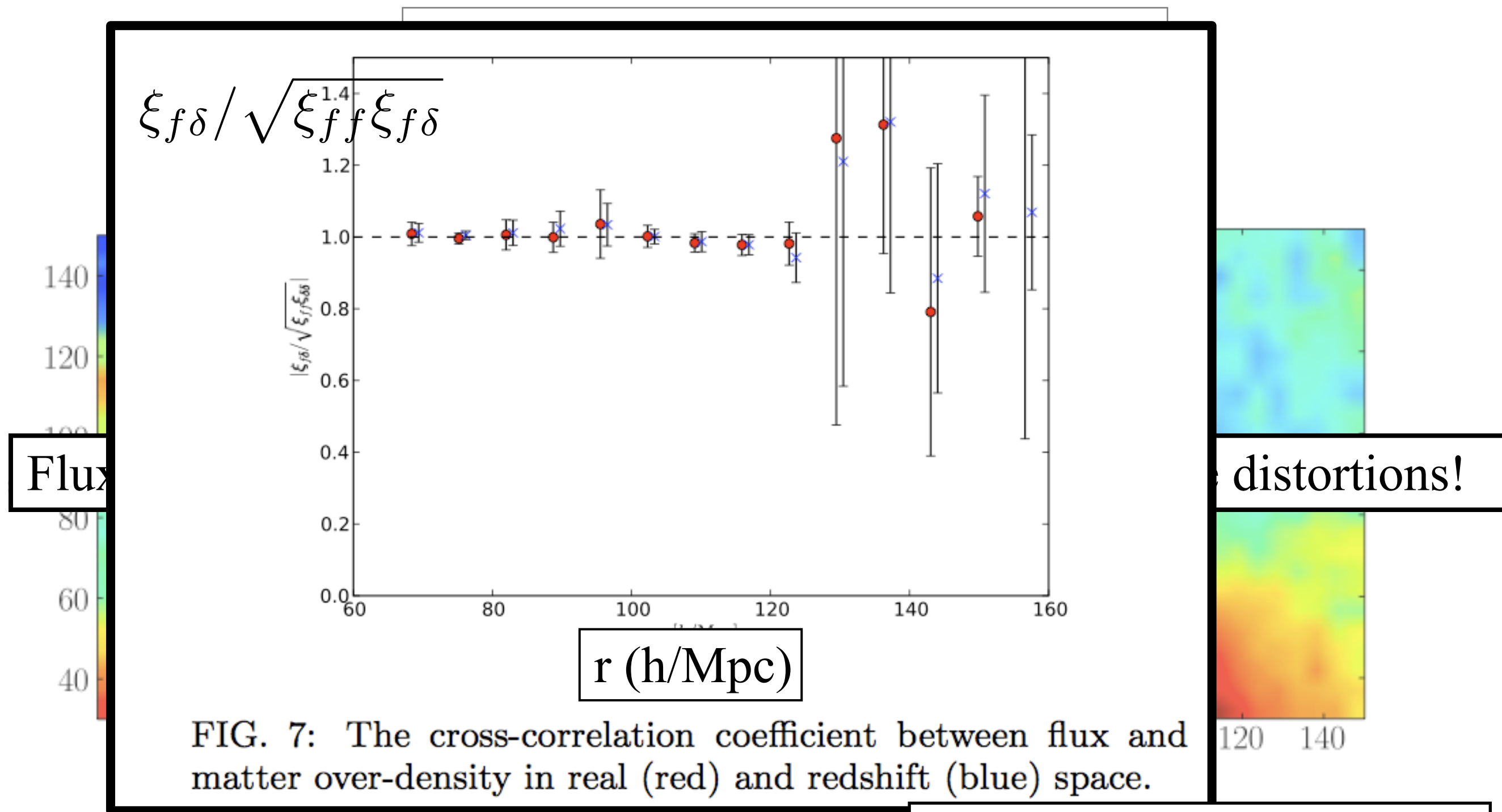


Flux traces matter quite well even when we include redshift space distortions!

Slosar, SH, White & Louis (2009)



# Lyman Alpha Forest: what can it do?



Slosar, SH, White & Louis (2009)

# Lyman Alpha Forest: what can it do?

Redshift Space Correlation function

Matter

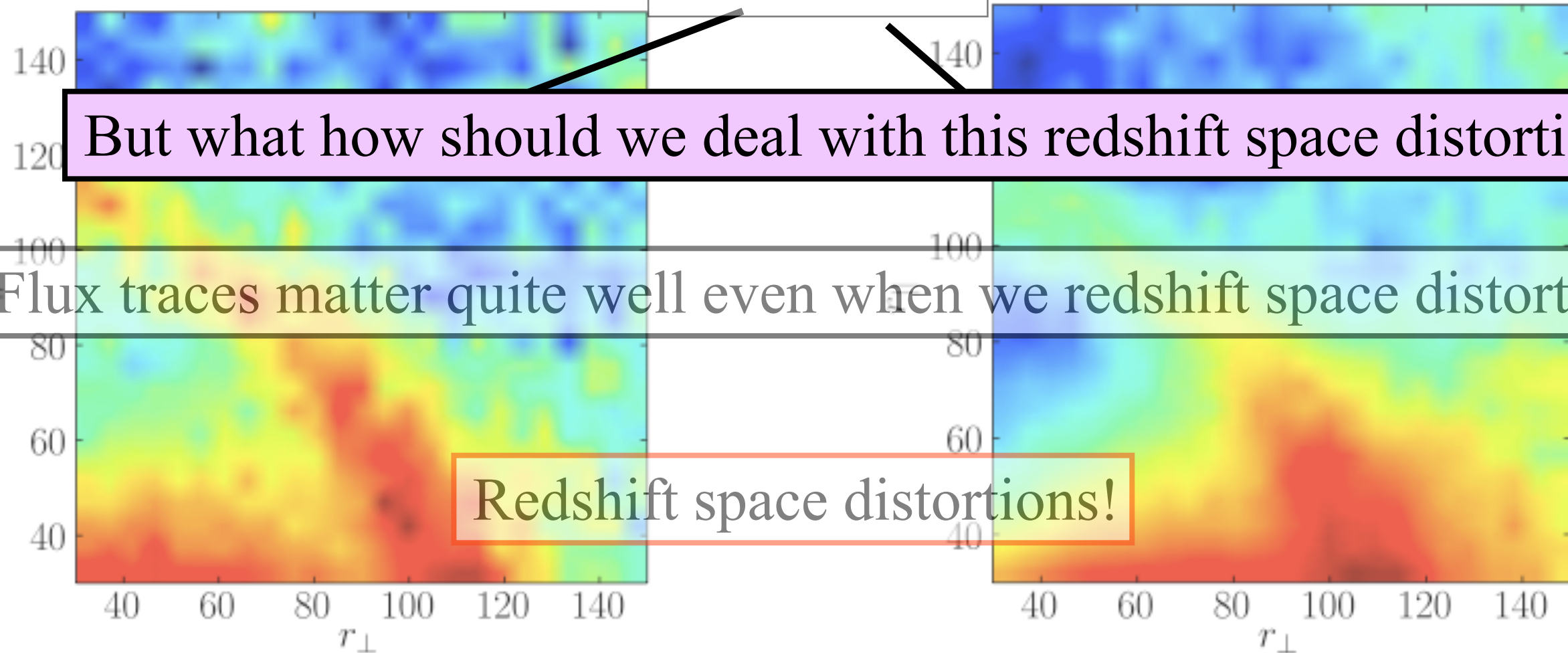
Flux

BAO feature

But what how should we deal with this redshift space distortion ?

Flux traces matter quite well even when we redshift space distortions!

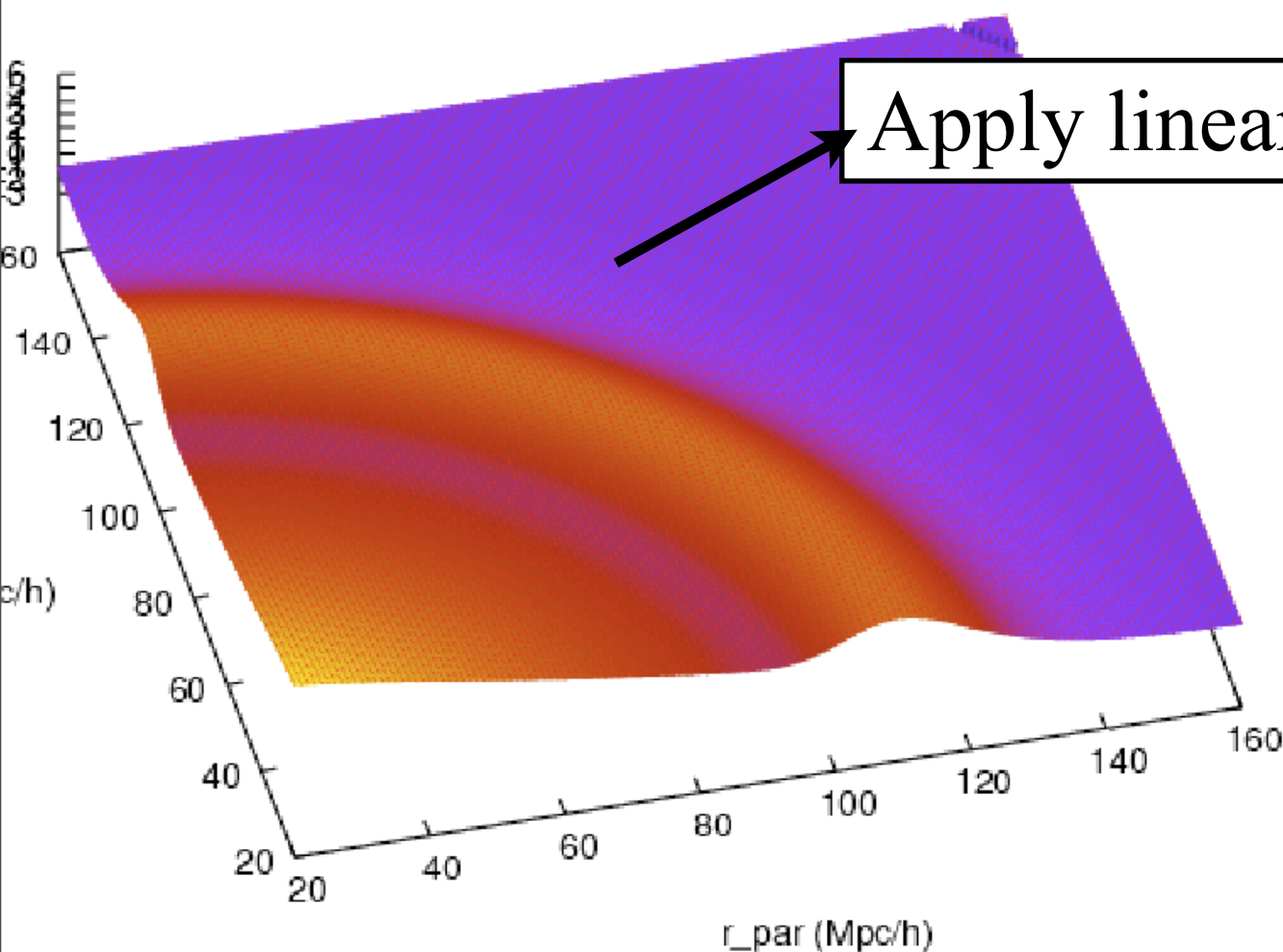
Redshift space distortions!



# Lyman Alpha Forest: what can it do?

No z-space distortion

z-space distortions



Apply linear Kaiser formula

$$\xi(r, \mu) = \sum_{\ell=0,2,4} L_{\ell}(\mu) \xi_{\ell}(r),$$

$$\xi_0(r) = C_0 \xi_R(r),$$

$$\xi_2(r) = C_2 (\xi_R(r) - \bar{\xi}(r)),$$

$$\xi_4(r) = C_4 (\xi_R(r) + 2.5 \bar{\xi}(r) - 3.5 \bar{\bar{\xi}}(r)),$$

$$\mu = r_{\text{par}} / |\vec{r}|$$

$$C_i = f_i(\beta)$$

$$\beta = d \ln \delta / d \ln a = \Omega_m^{0.6}$$

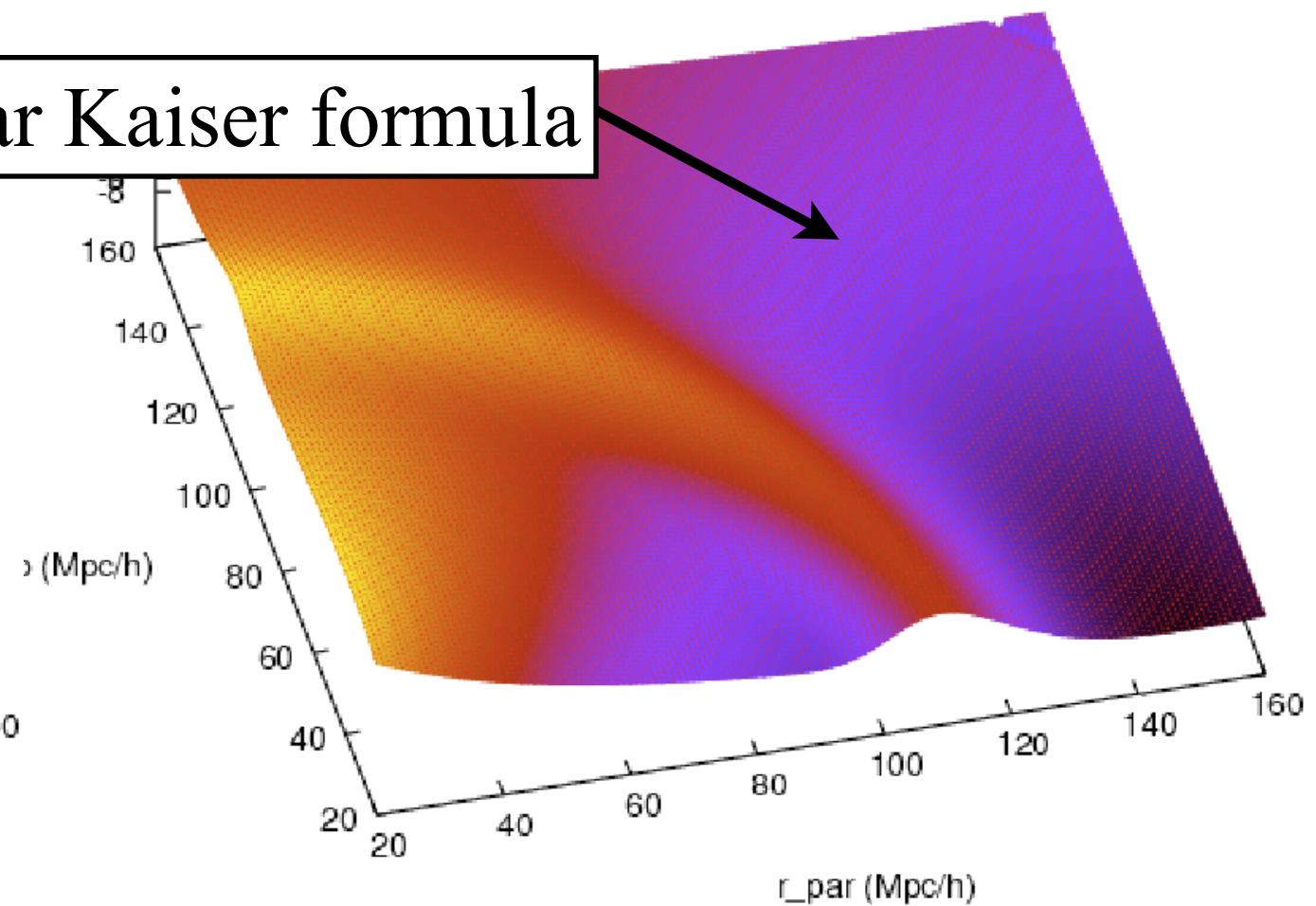
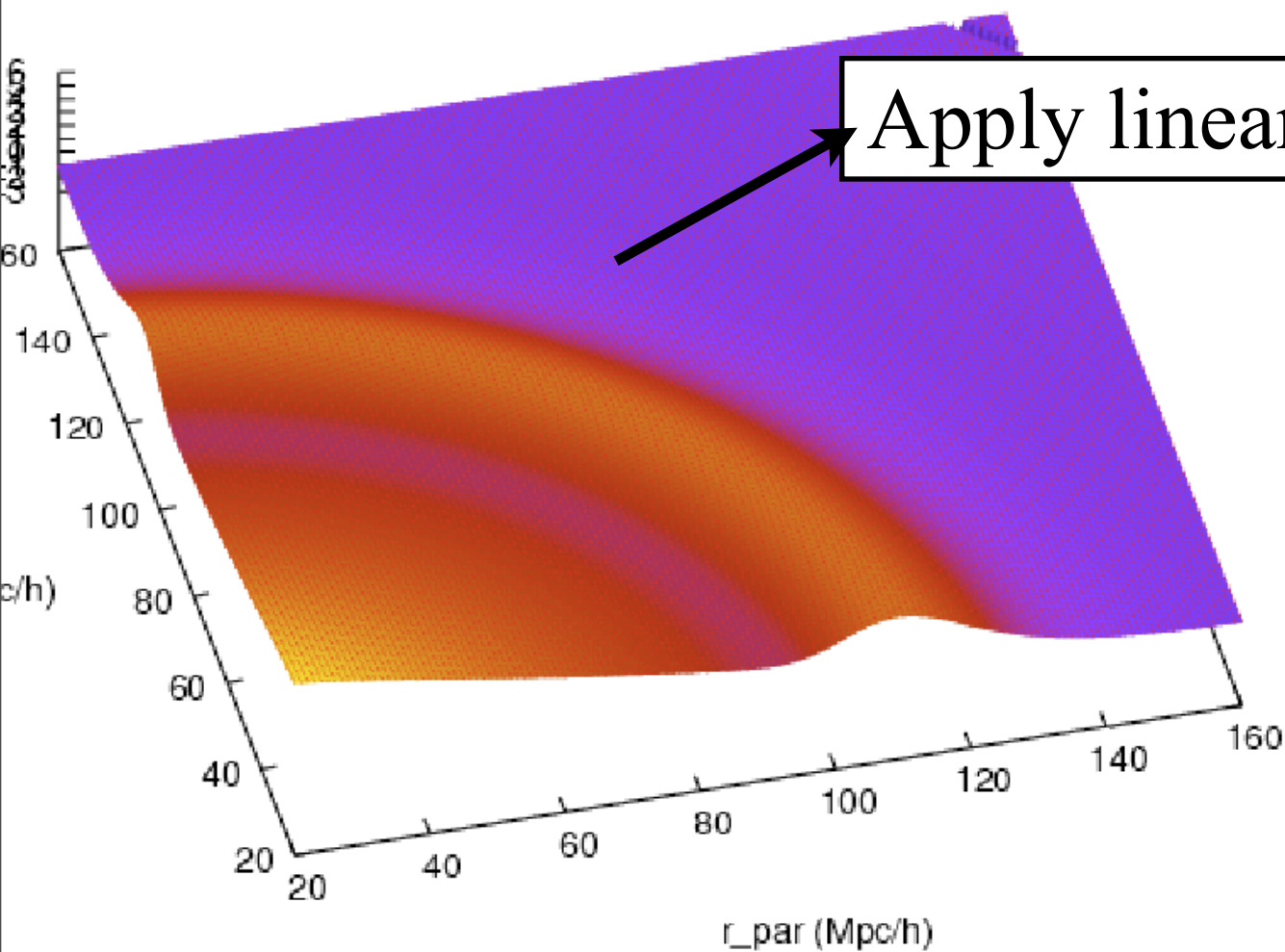


# Lyman Alpha Forest: what can it do?

No z-space distortion

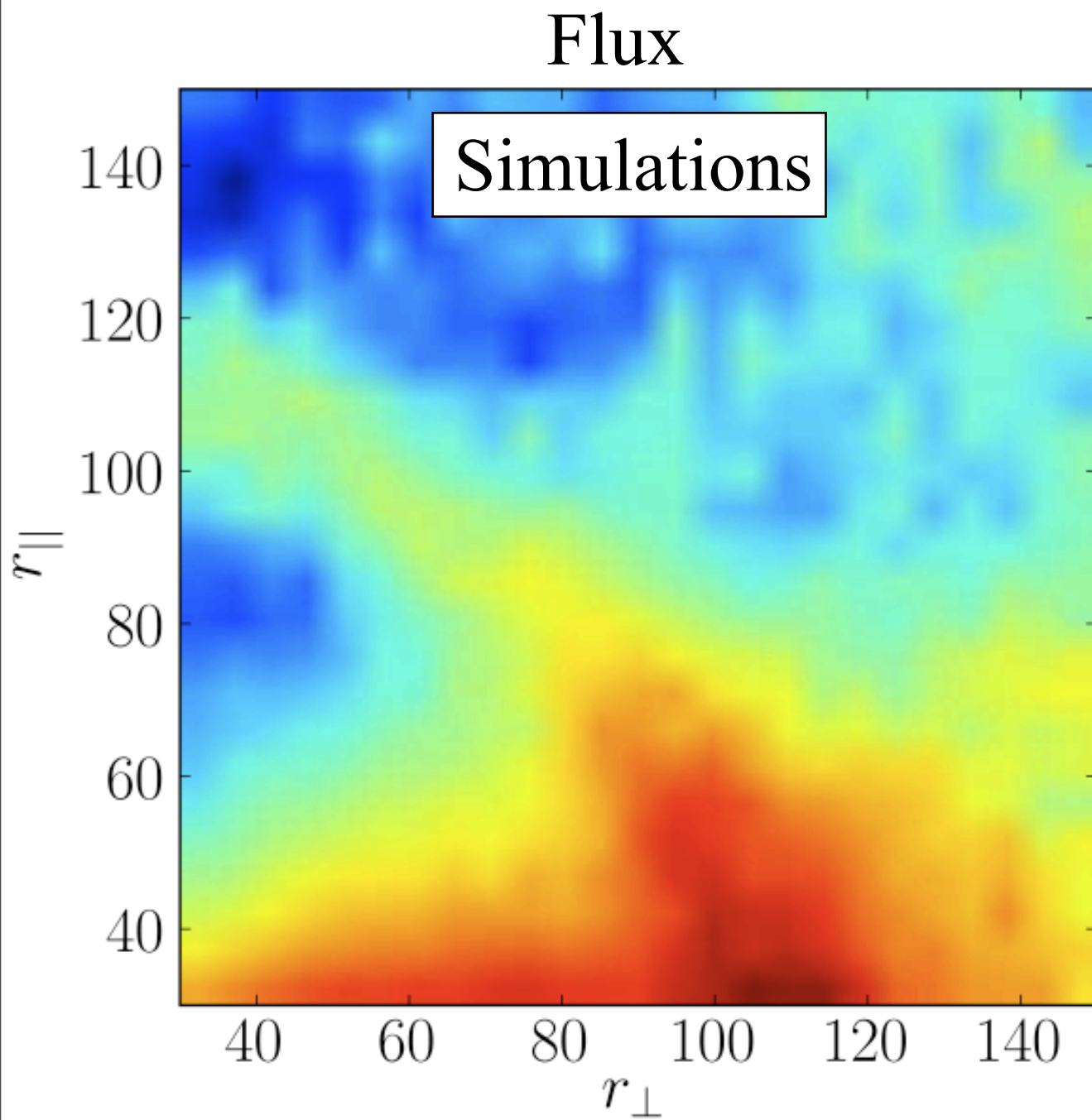
z-space distortions

Apply linear Kaiser formula

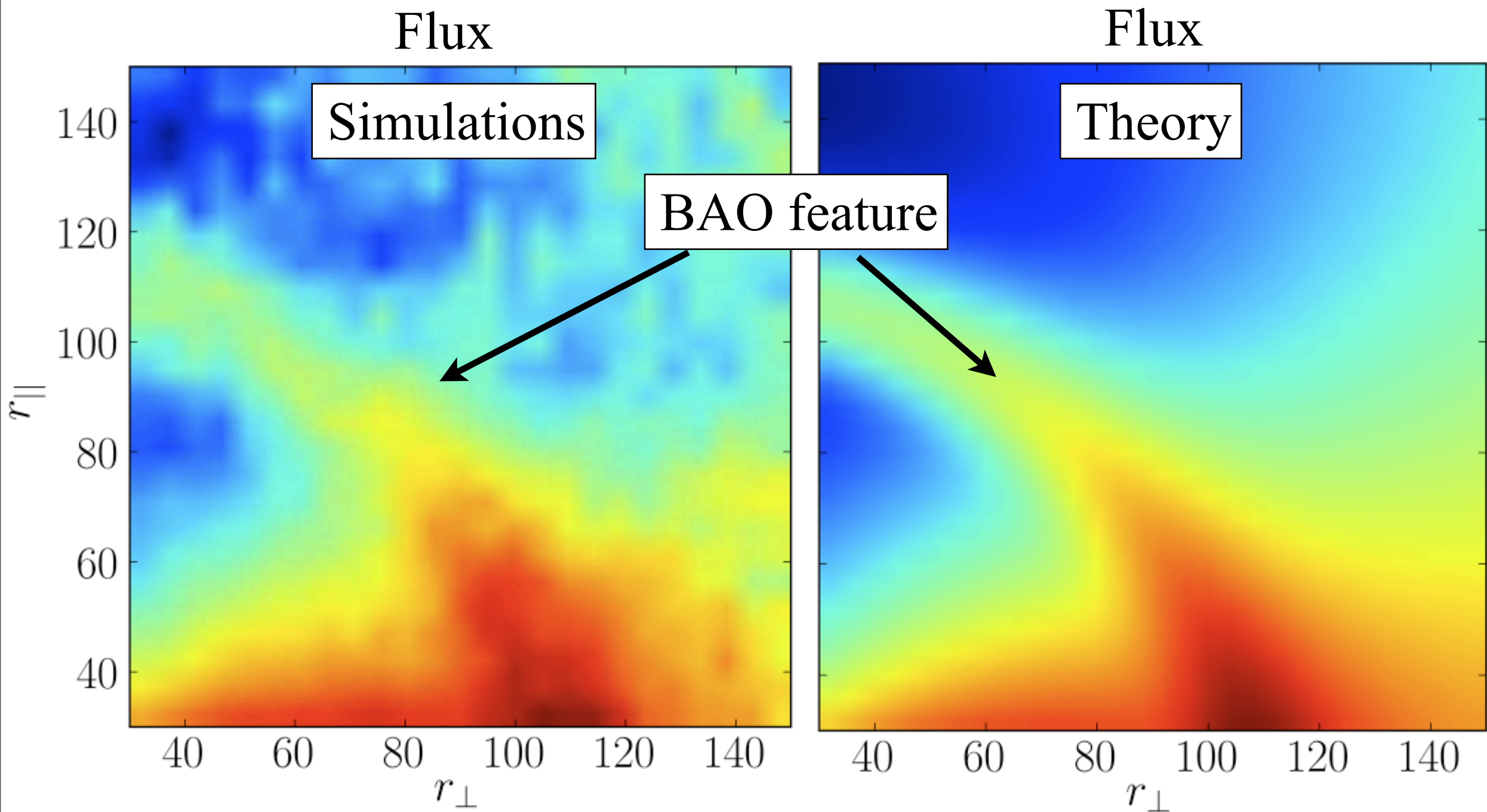




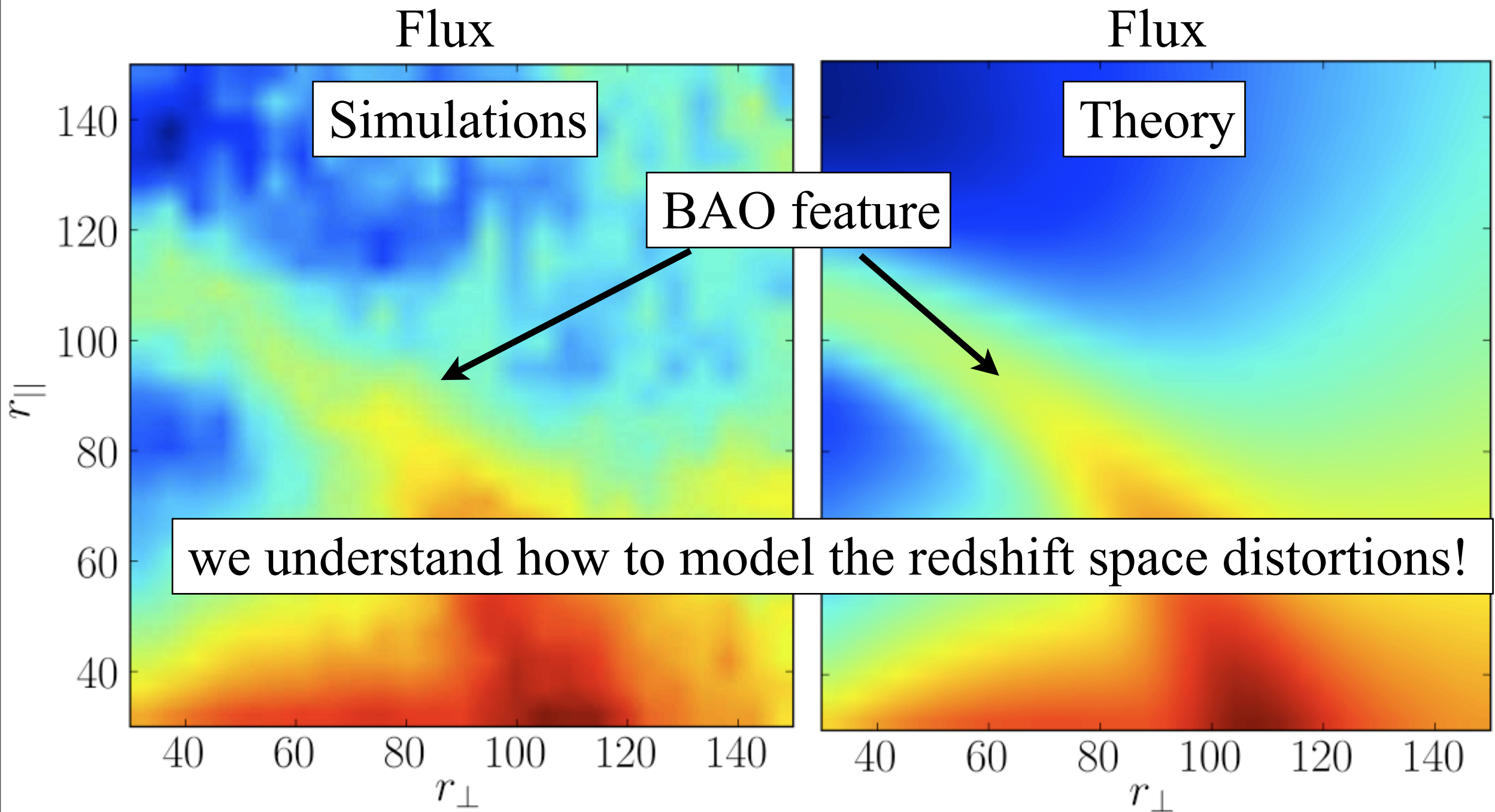
# Lyman Alpha Forest: what can it do?



# Lyman Alpha Forest: what can it do?



# Lyman Alpha Forest: what can it do?



Slosar, SH, White & Louis (2009)

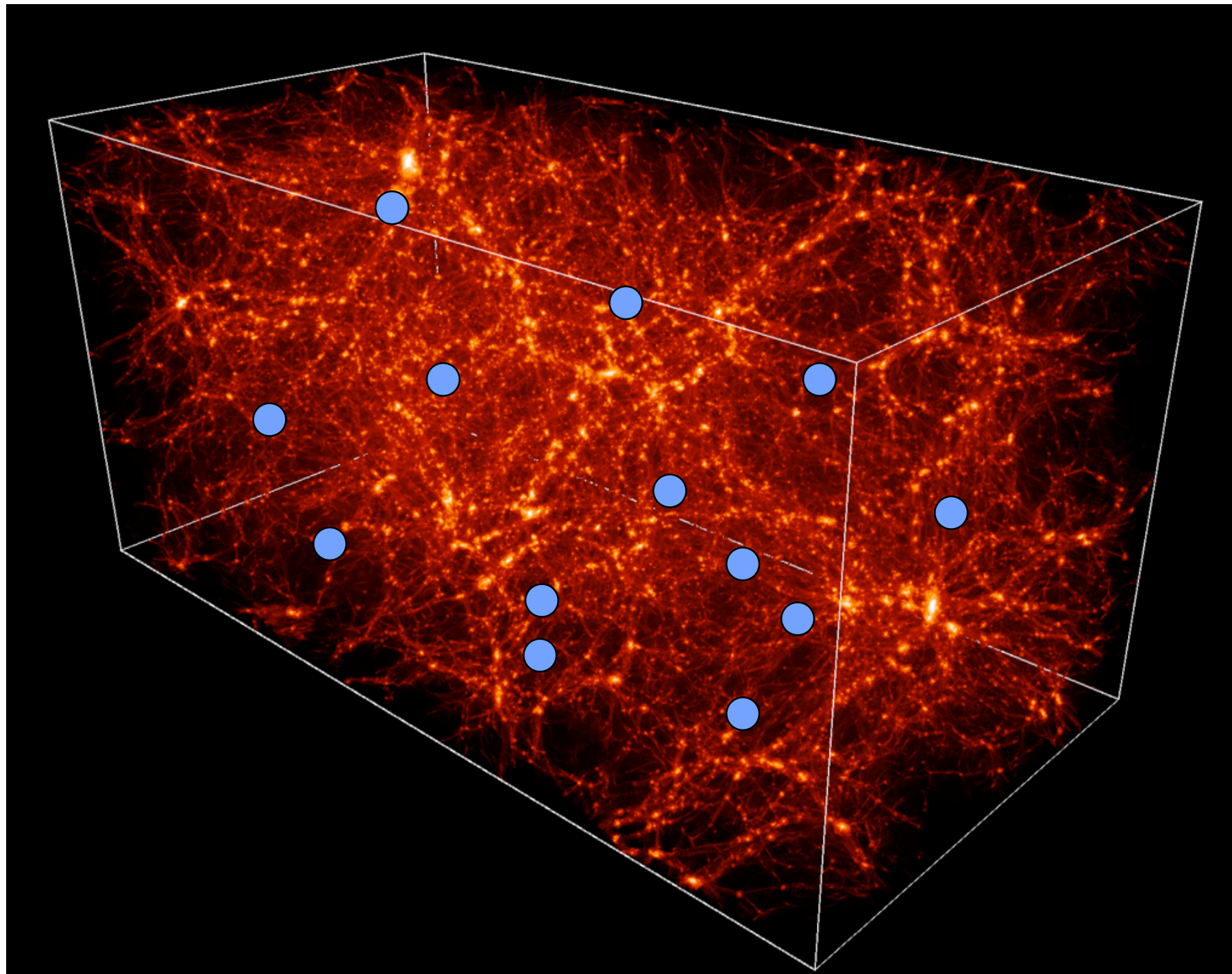
# Possible Systematics



- **UV background fluctuations**
- **Metal Line contaminations**
- **Continuum subtractions**
- **Other IGM physics? ...**

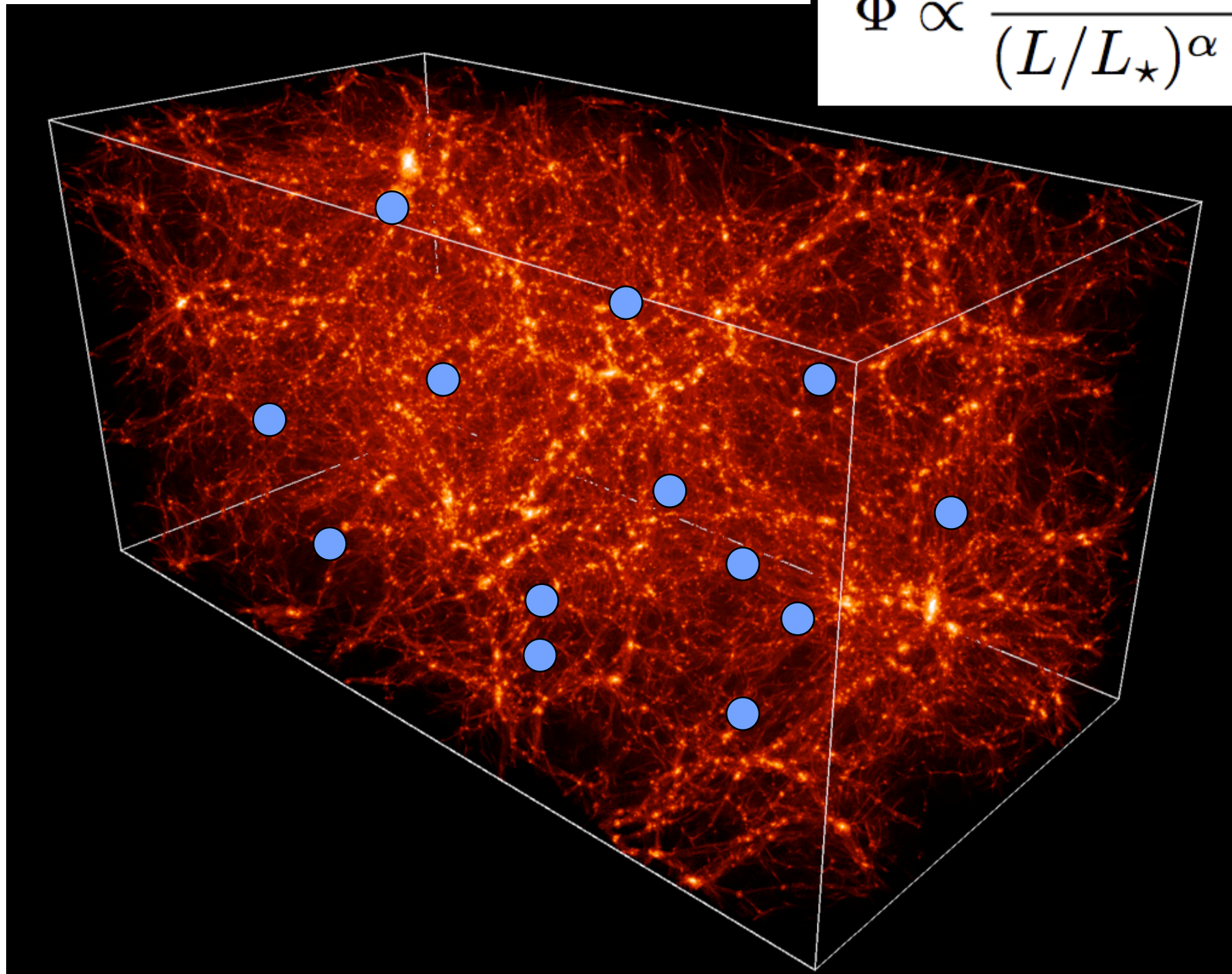


# Possible Systematics: UV background fluctuations



# Possible Systematics: UV background fluctuations

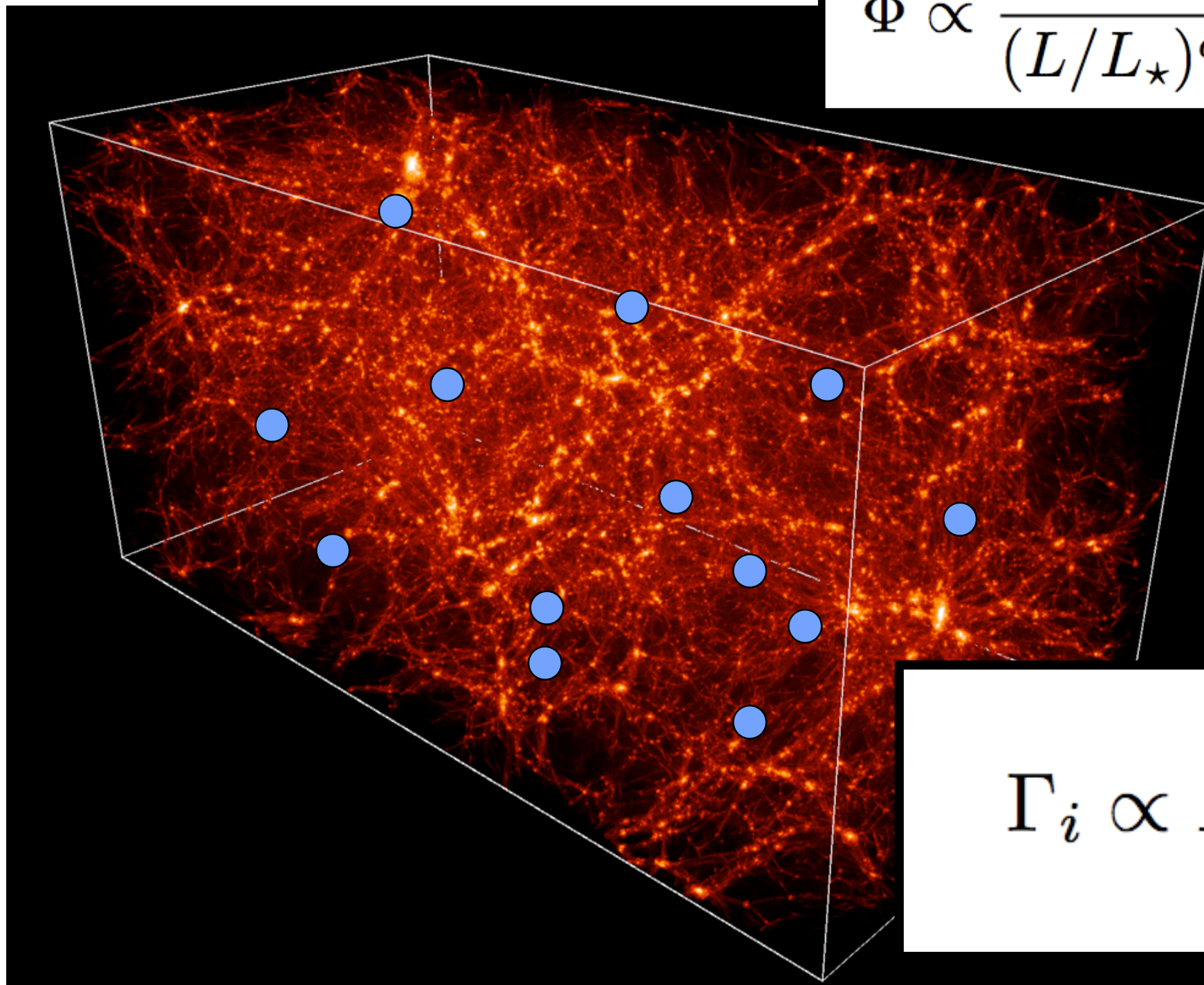
$$\Phi \propto \frac{1}{(L/L_{\star})^{\alpha} + (L/L_{\star})^{\beta}}$$





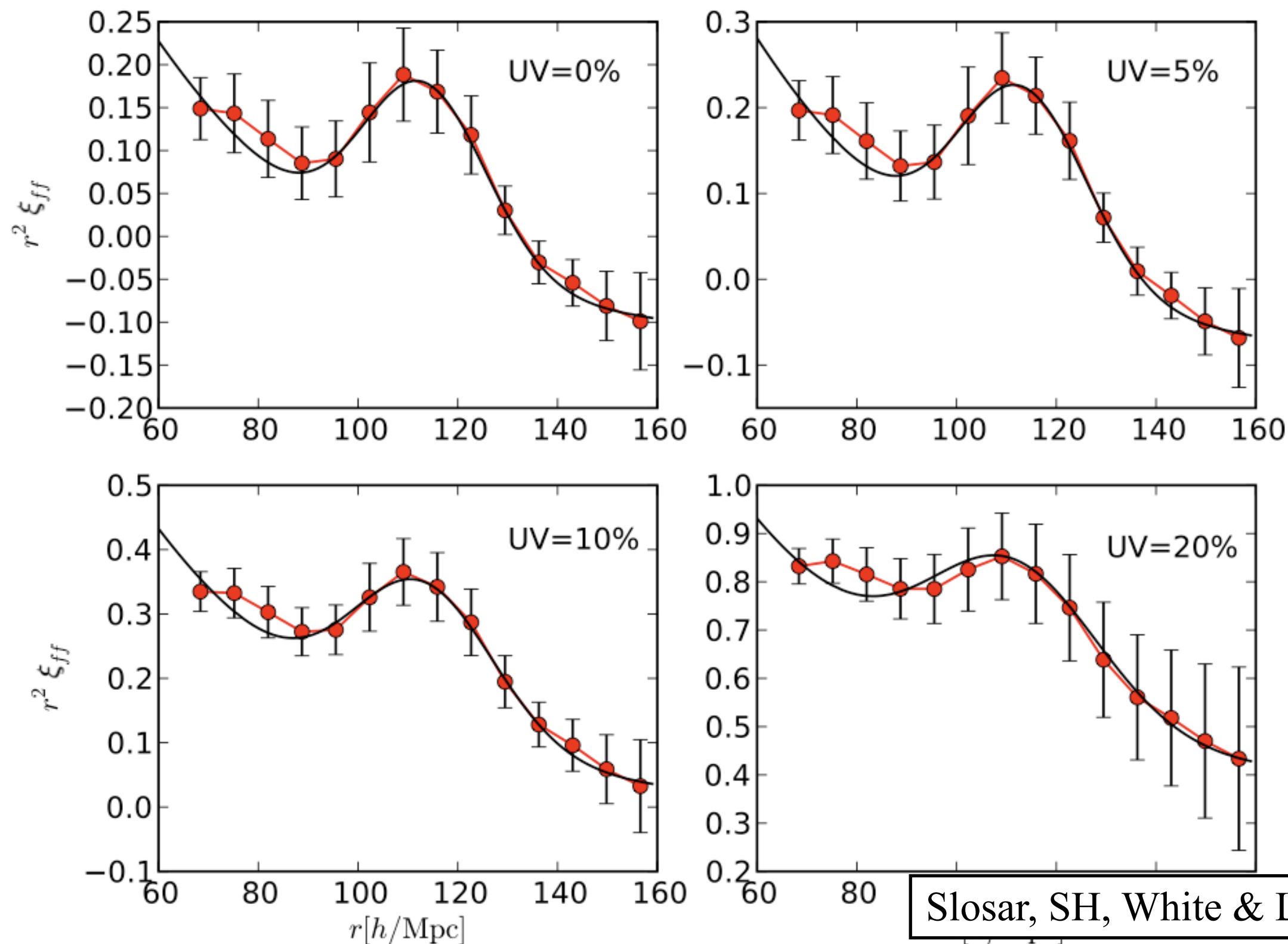
# Possible Systematics: UV background fluctuations

$$\Phi \propto \frac{1}{(L/L_{\star})^{\alpha} + (L/L_{\star})^{\beta}}$$



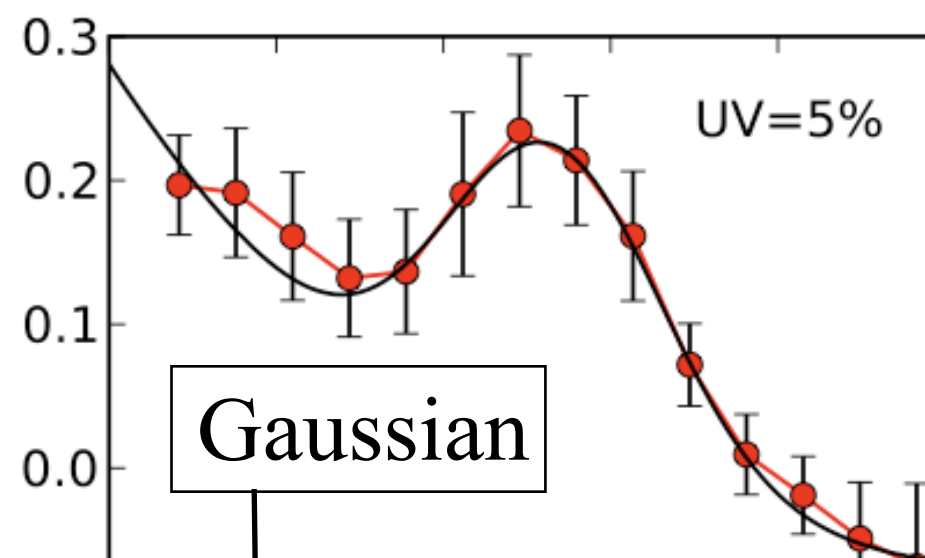
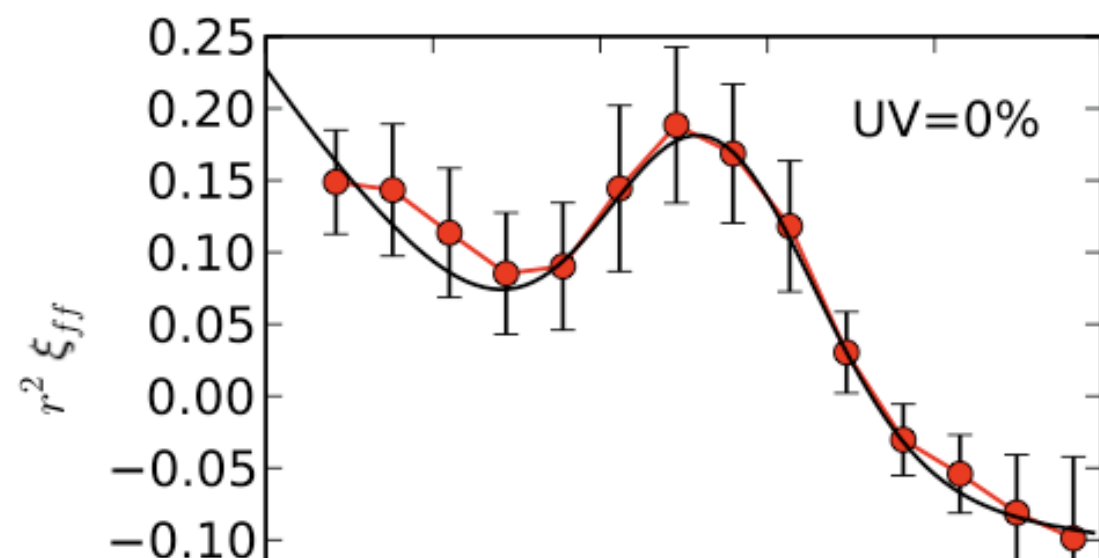
$$\Gamma_i \propto L_i \frac{e^{-r_i/r_0}}{4\pi r_i^2}$$

# Possible Systematics: UV background fluctuations

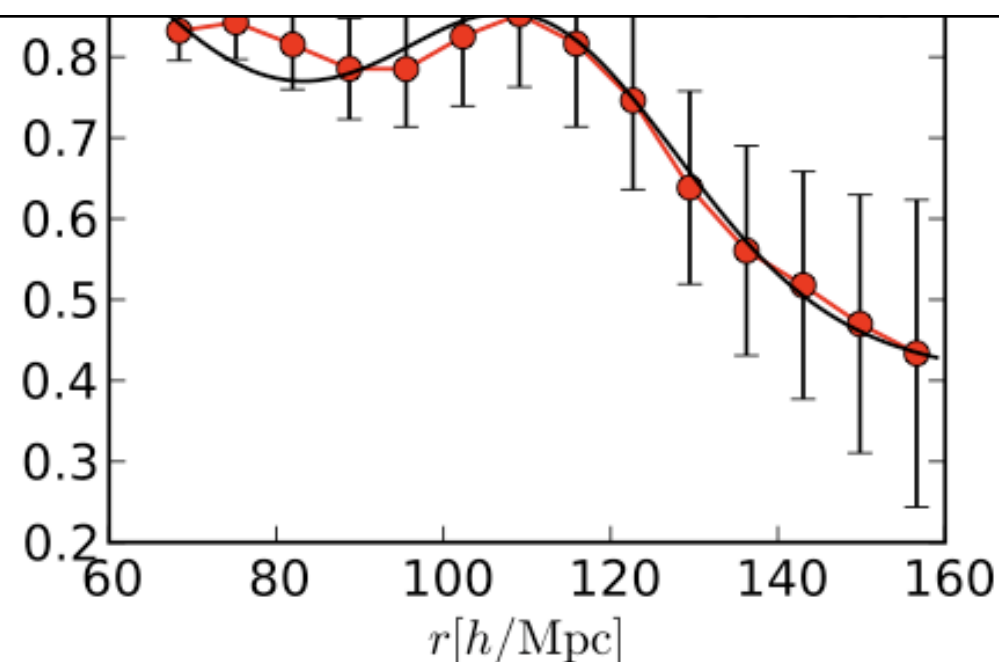
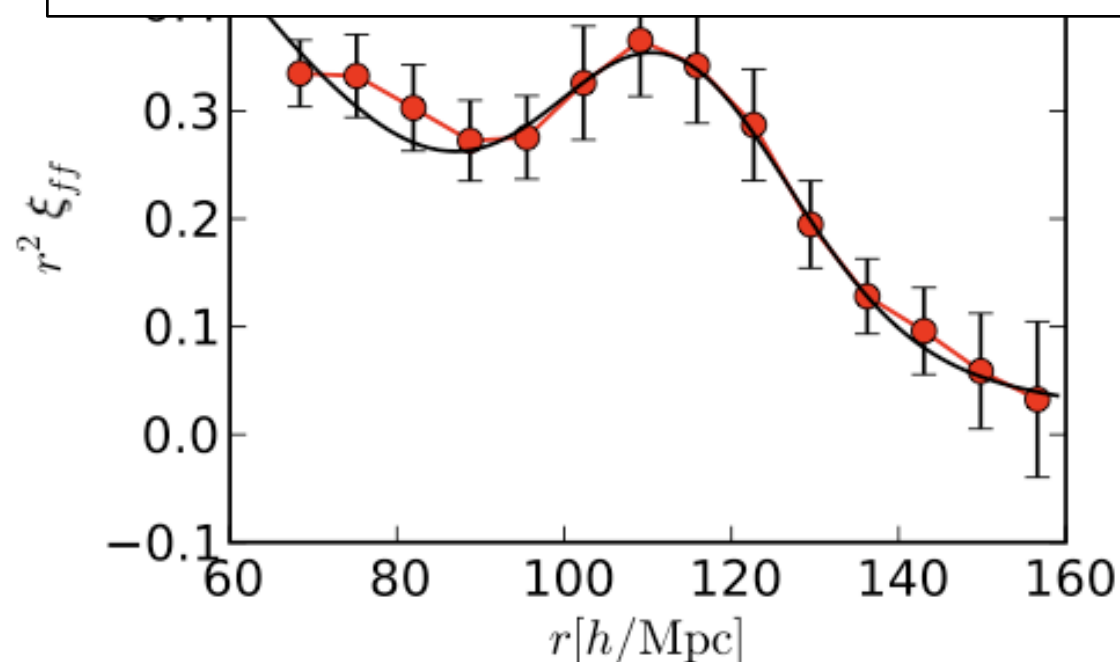




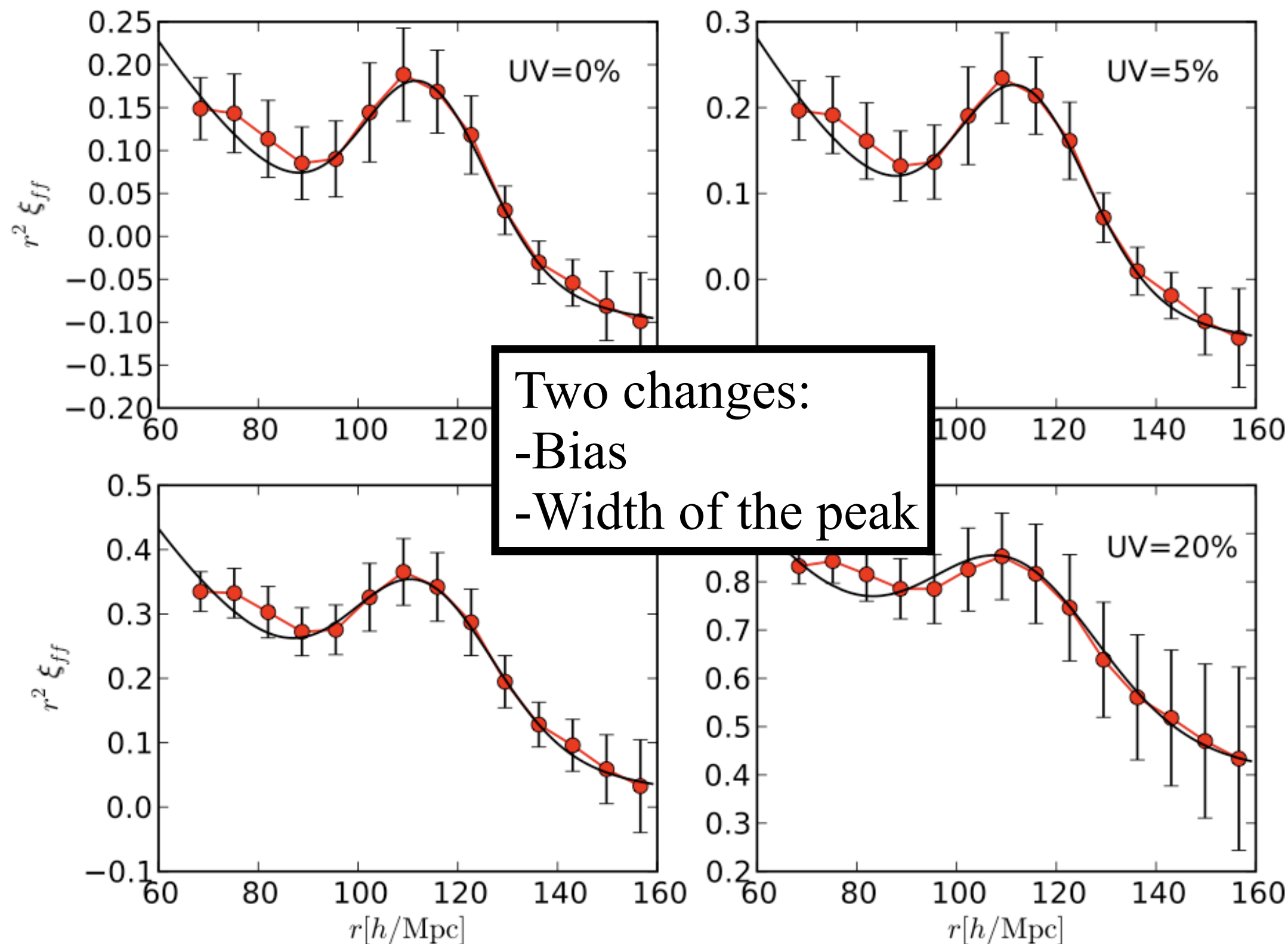
# Possible Systematics: UV background fluctuations



$$\xi(r) = b^2 \left( \xi_{\text{nb}}(r) + \frac{h}{r^2} G(r_{\text{peak}}, \sigma_{\text{peak}}) \right) + \lambda$$

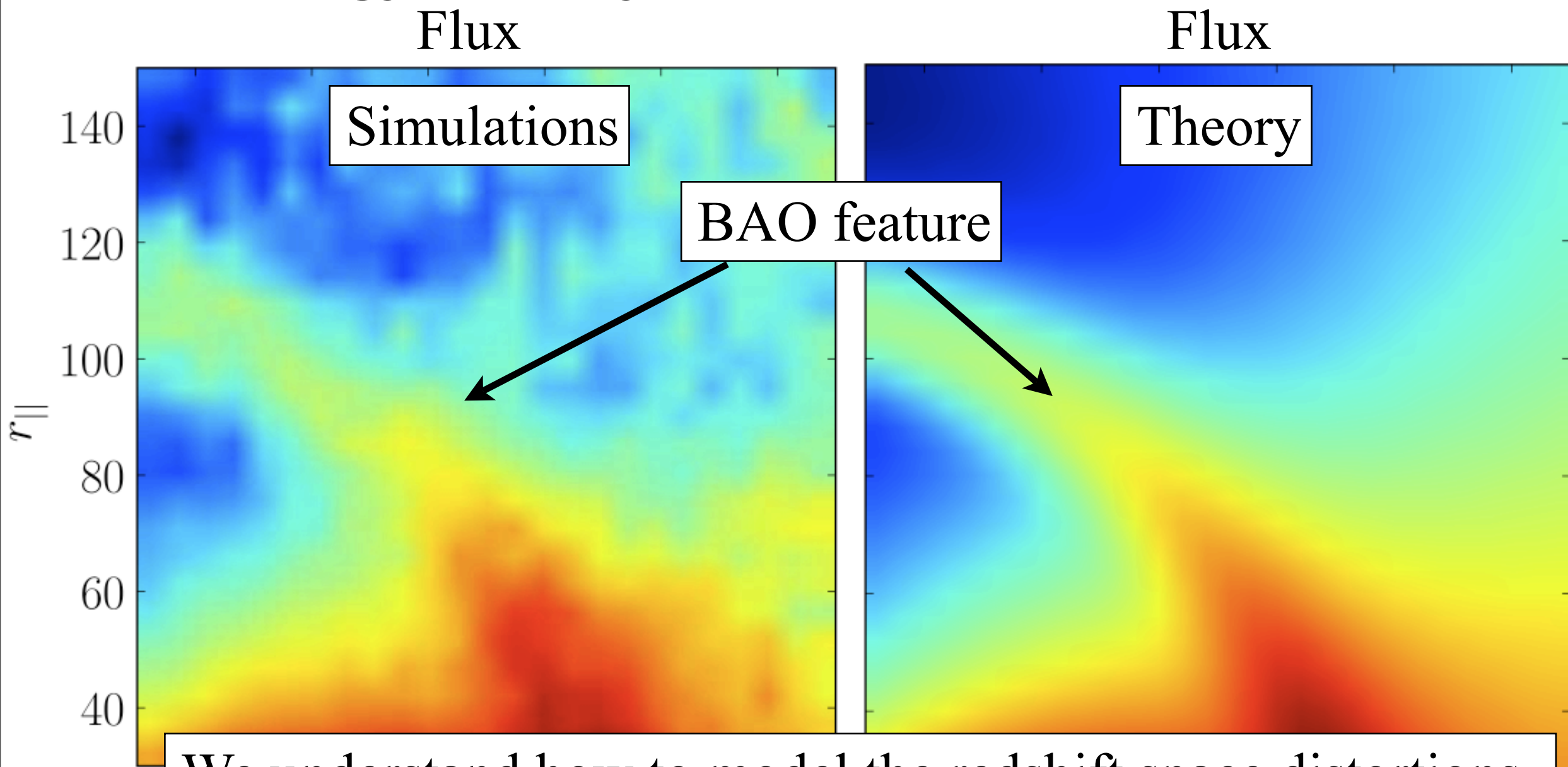


# Possible Systematics: UV background fluctuations



# Lyman Alpha Forest: what can it do?

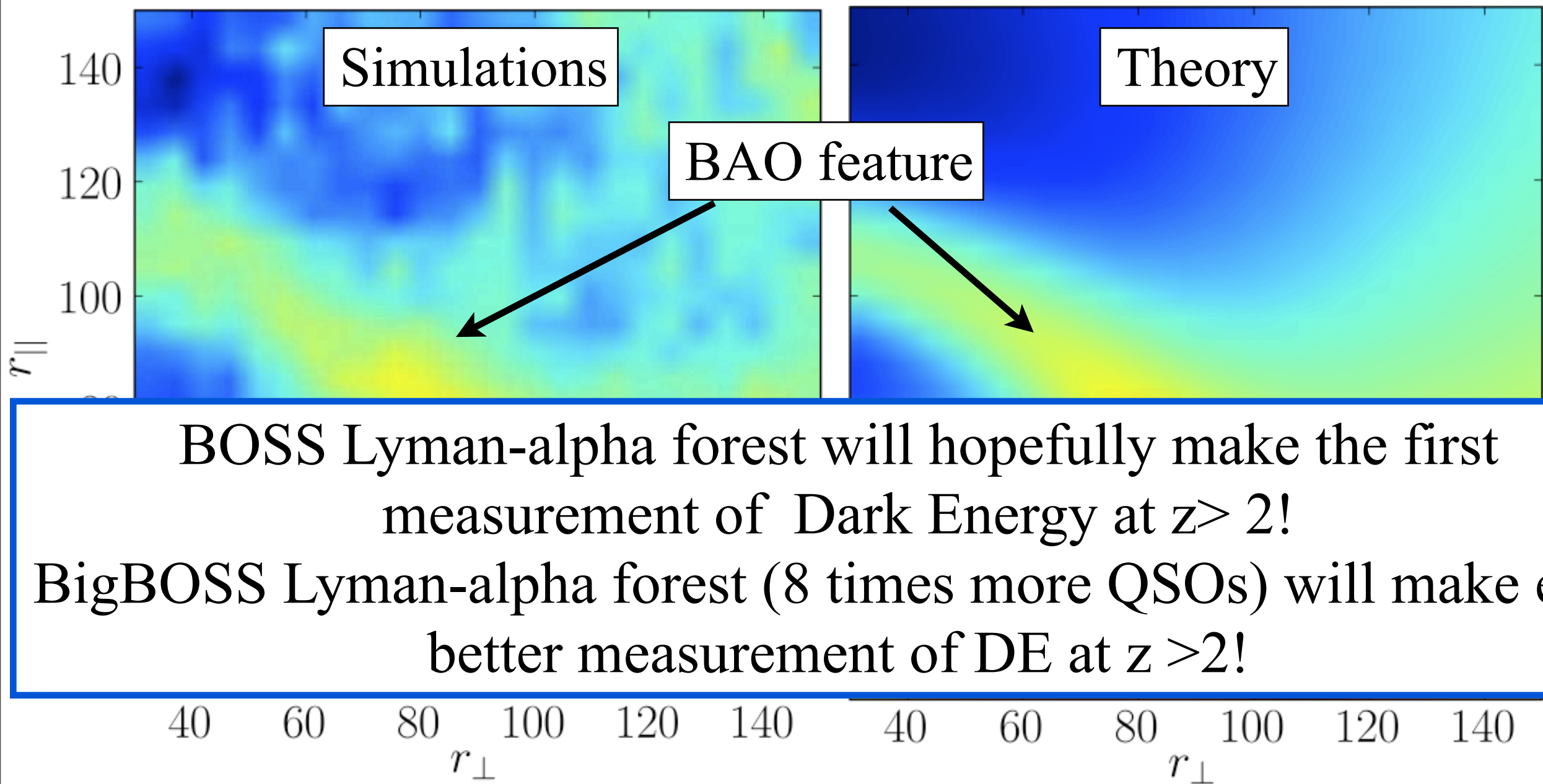
- **Dark Energy via Baryon Acoustic Oscillations**



We understand how to model the redshift space distortions, and approximately what happens when we include systematics such as UV background fluctuations.

# Lyman Alpha Forest: what can it do?

- Dark Energy via Baryon Acoustic Oscillations



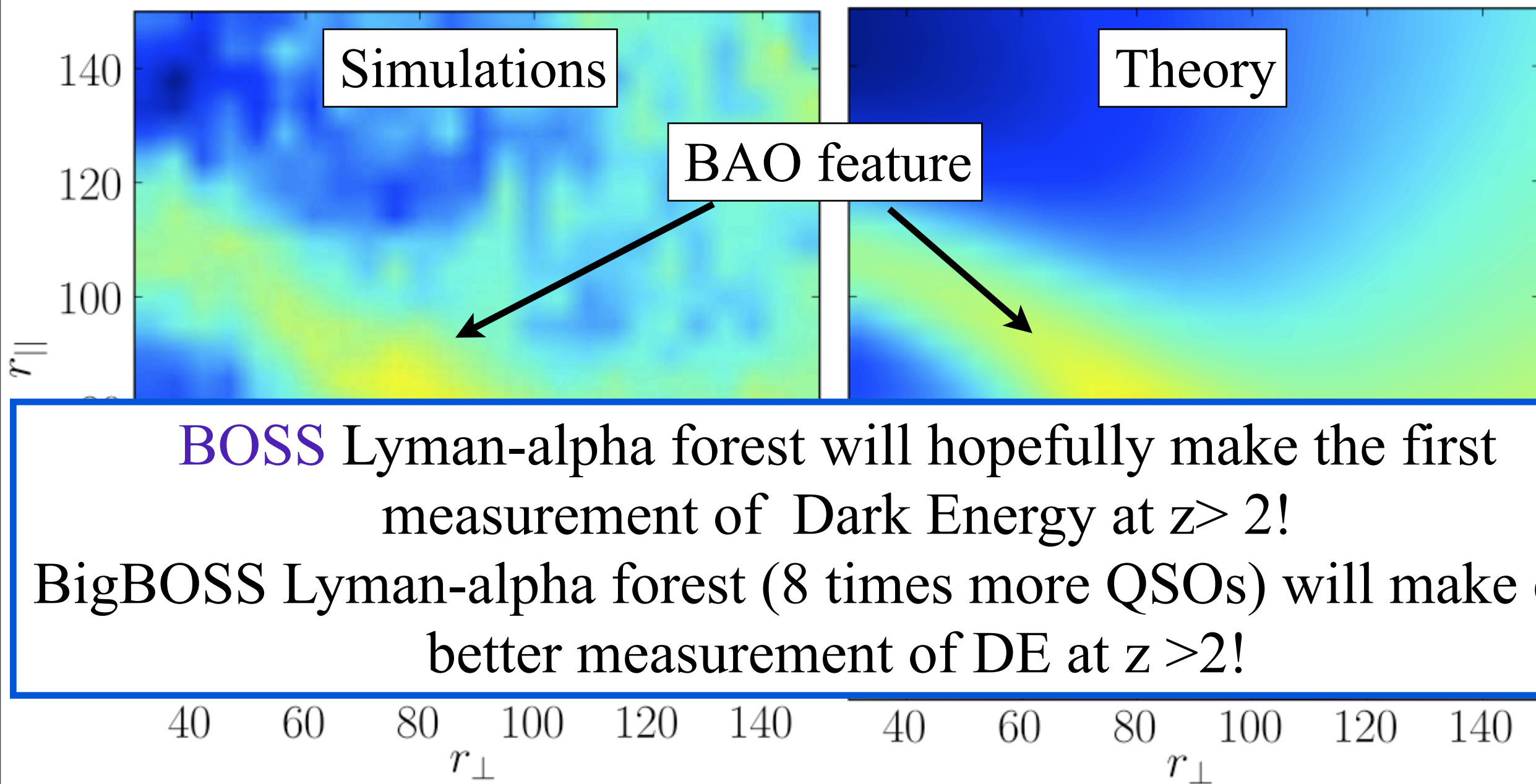
BOSS Lyman-alpha forest will hopefully make the first measurement of Dark Energy at  $z > 2$ !

BigBOSS Lyman-alpha forest (8 times more QSOs) will make even better measurement of DE at  $z > 2$ !



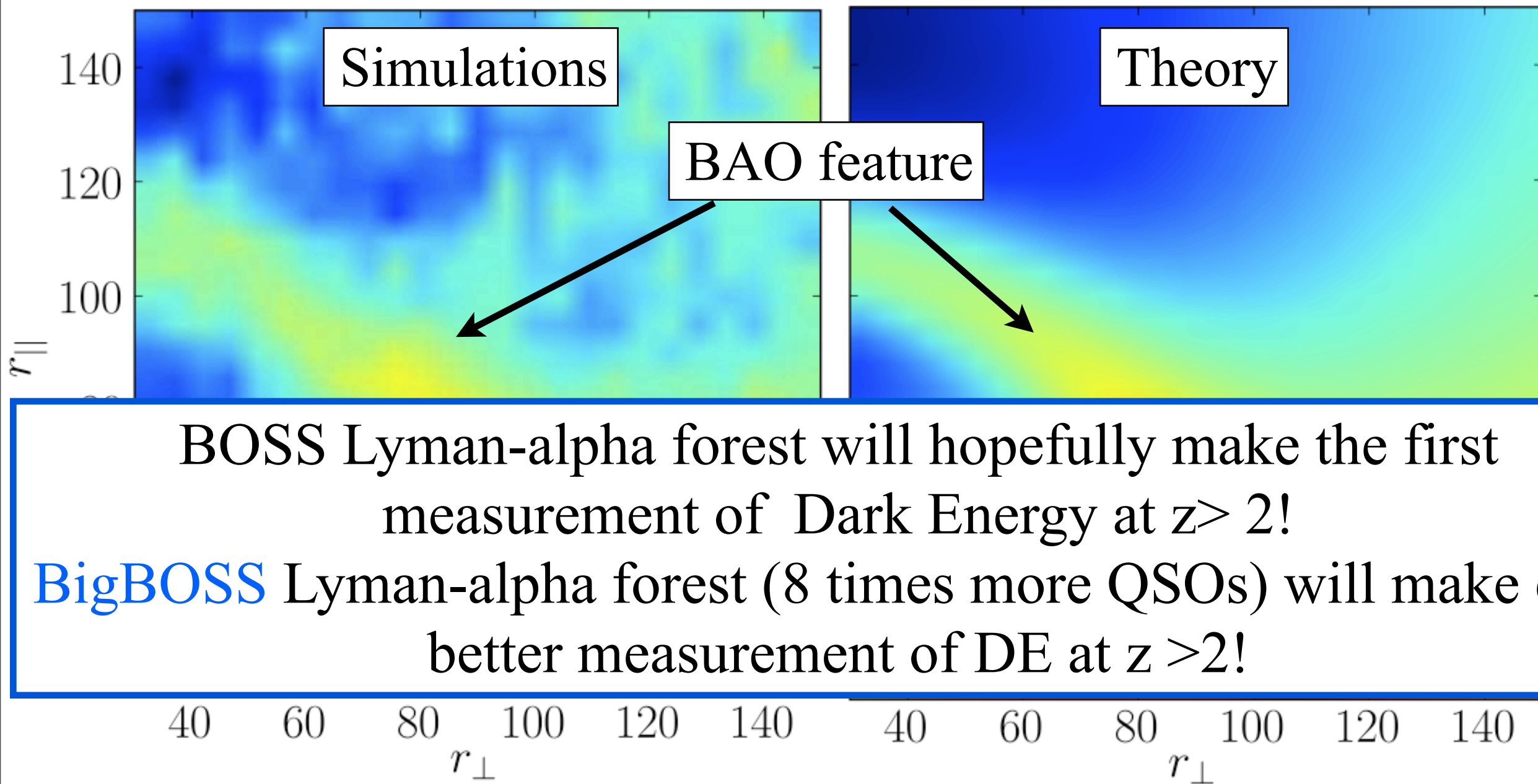
# Lyman Alpha Forest: what can it do?

- **Dark Energy via Baryon Acoustic Oscillations**



# Lyman Alpha Forest: what can it do?

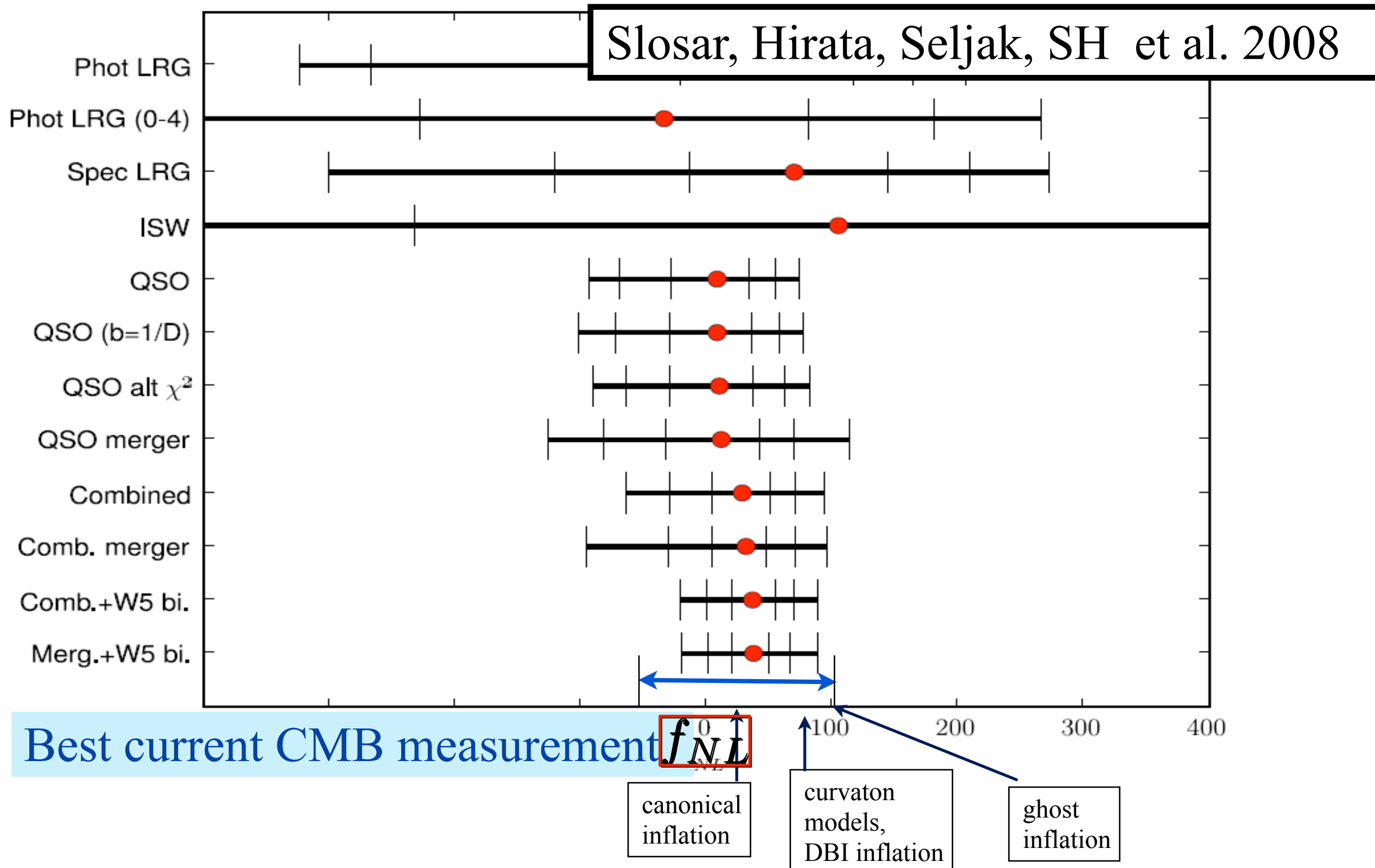
- Dark Energy via Baryon Acoustic Oscillations



- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations**
    - Dark Energy
  - **Scale Dependent Bias**
    - Primordial Non-gaussianities ( $f_{\text{nl}}$ )
- **Conclusion**

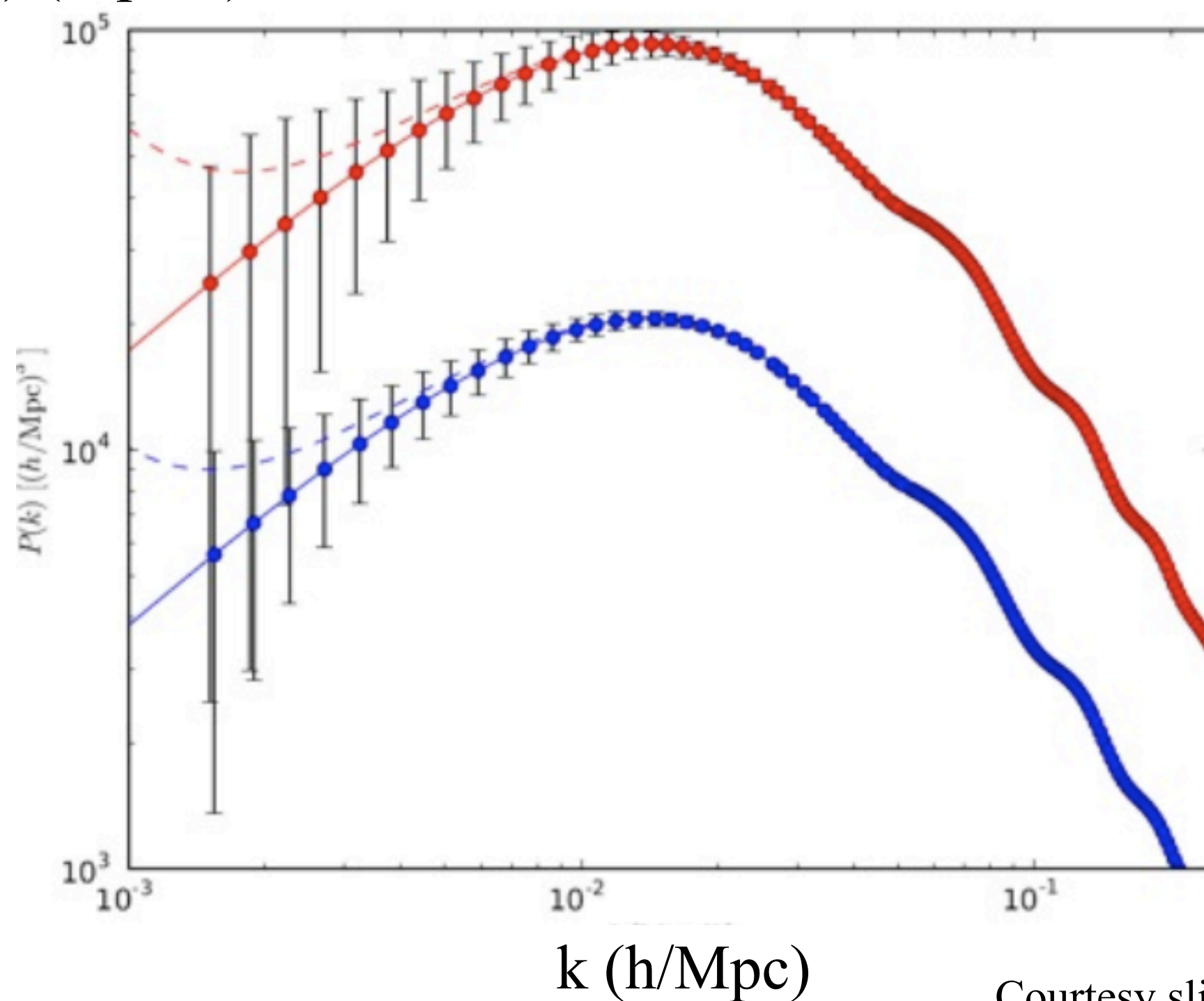
# Lyman Alpha Forest: what can it do?

## —Non-gaussianities in Early Universe



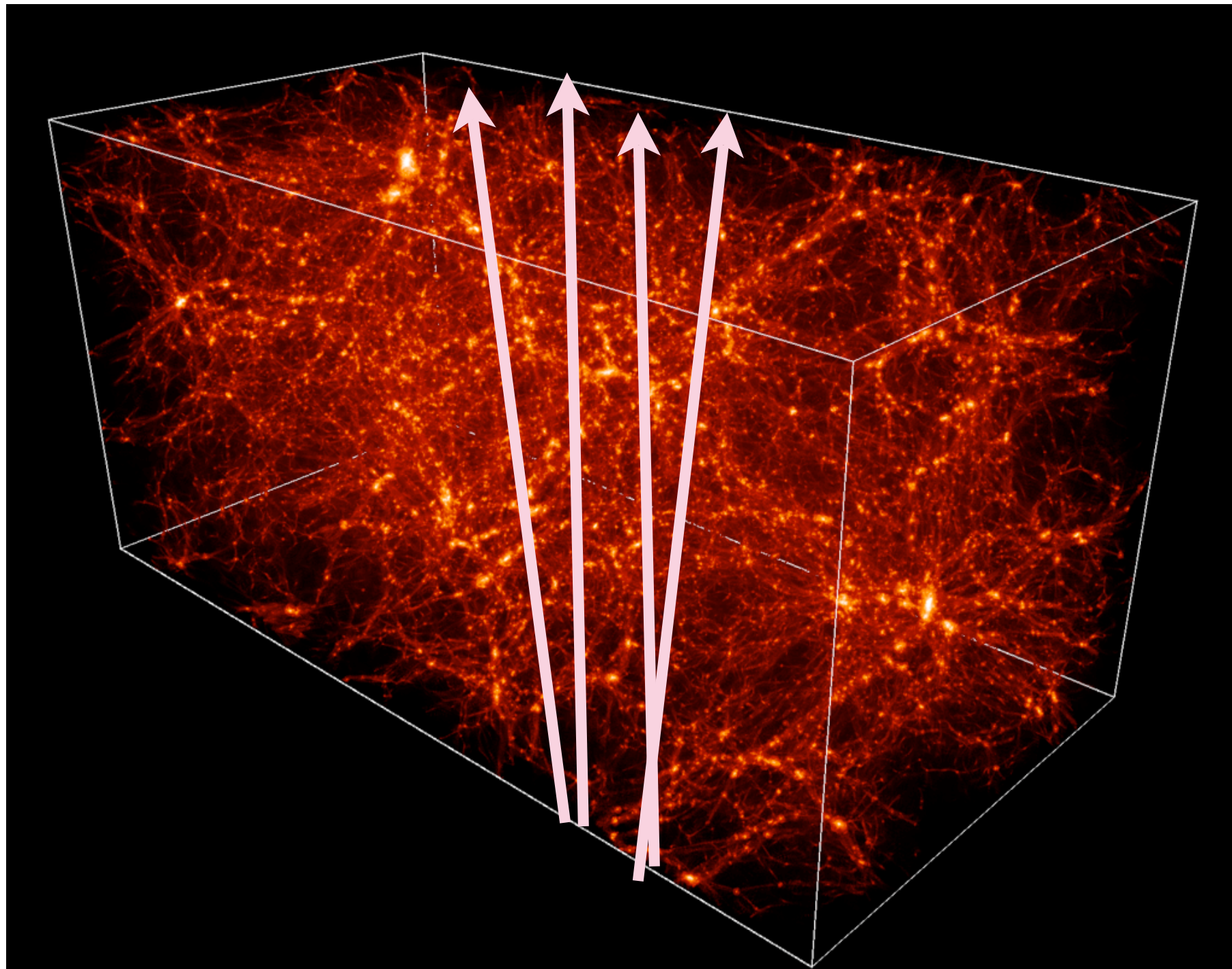


$P(k) \text{ (Mpc/h)}^3$

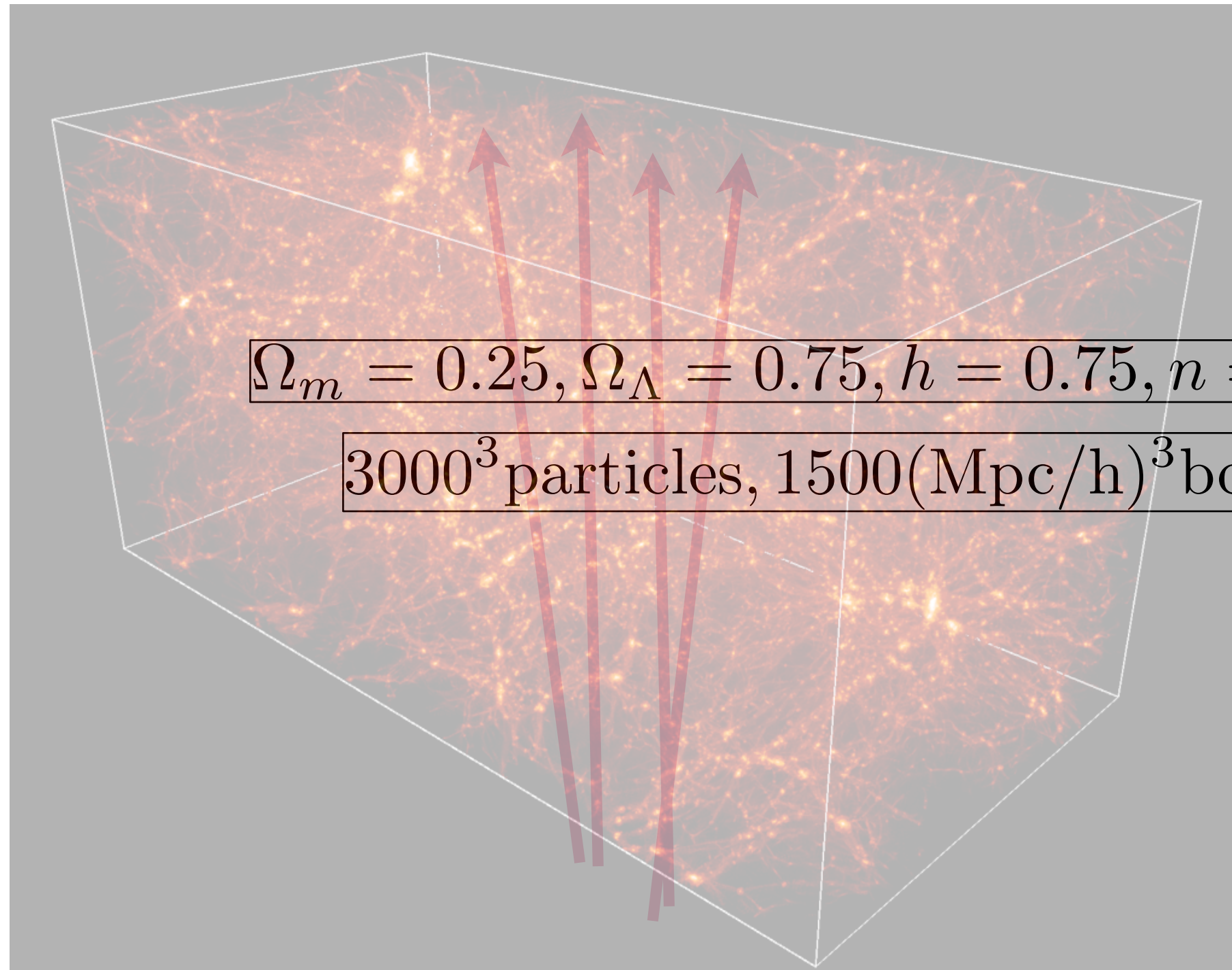


Courtesy slide from Anze Slosar

# Lyman Alpha Forest: what can it do?



# Lyman Alpha Forest: what can it do?

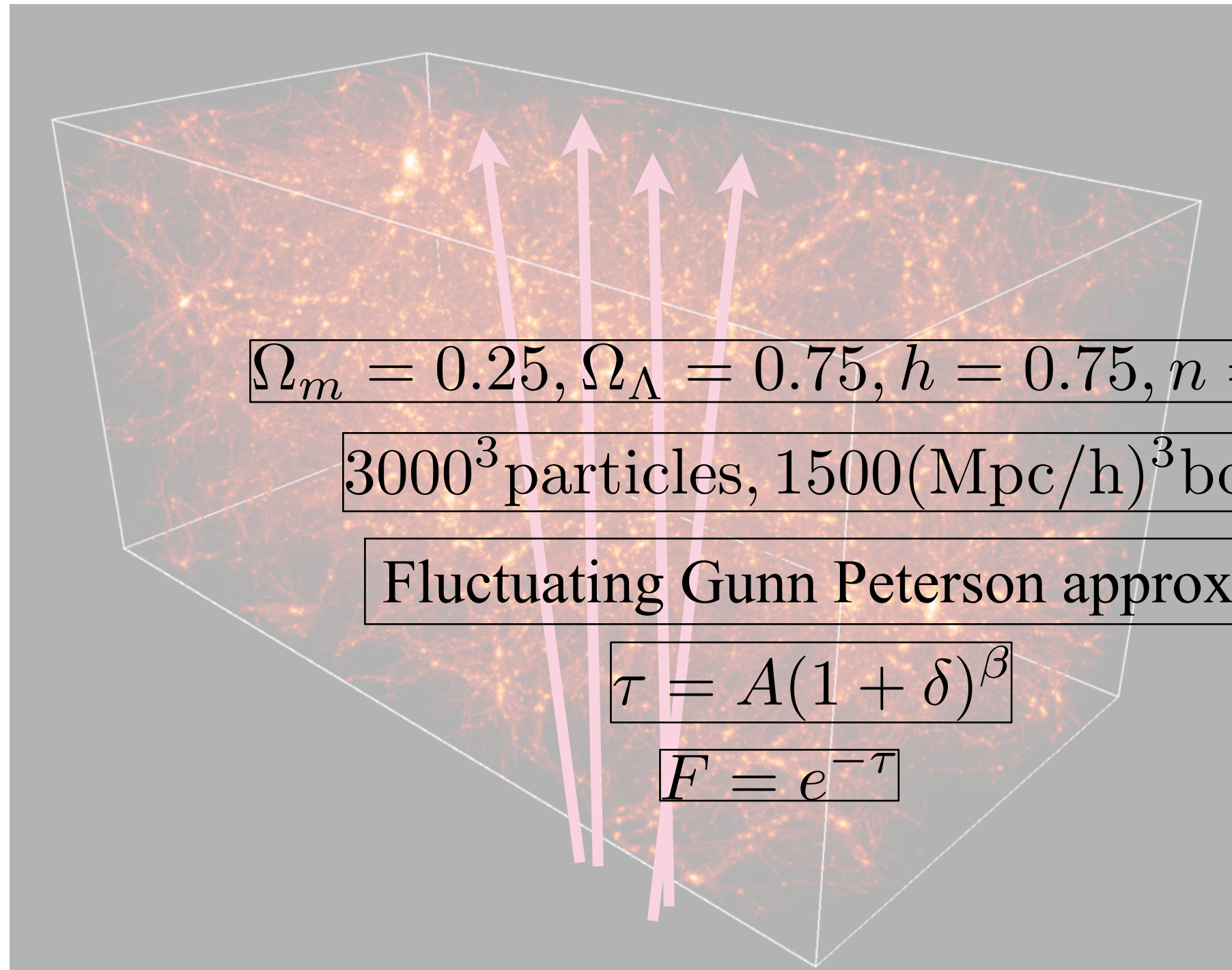


$$\Omega_m = 0.25, \Omega_\Lambda = 0.75, h = 0.75, n = 0.97, \sigma_8 = 0.8$$

$3000^3$  particles,  $1500(\text{Mpc}/h)^3$  box,  $3000^3$  grid



# Lyman Alpha Forest: what can it do?



$$\Omega_m = 0.25, \Omega_\Lambda = 0.75, h = 0.75, n = 0.97, \sigma_8 = 0.8$$

$$3000^3 \text{ particles}, 1500(\text{Mpc}/h)^3 \text{ box}, 3000^3 \text{ grid}$$

Fluctuating Gunn Peterson approximation

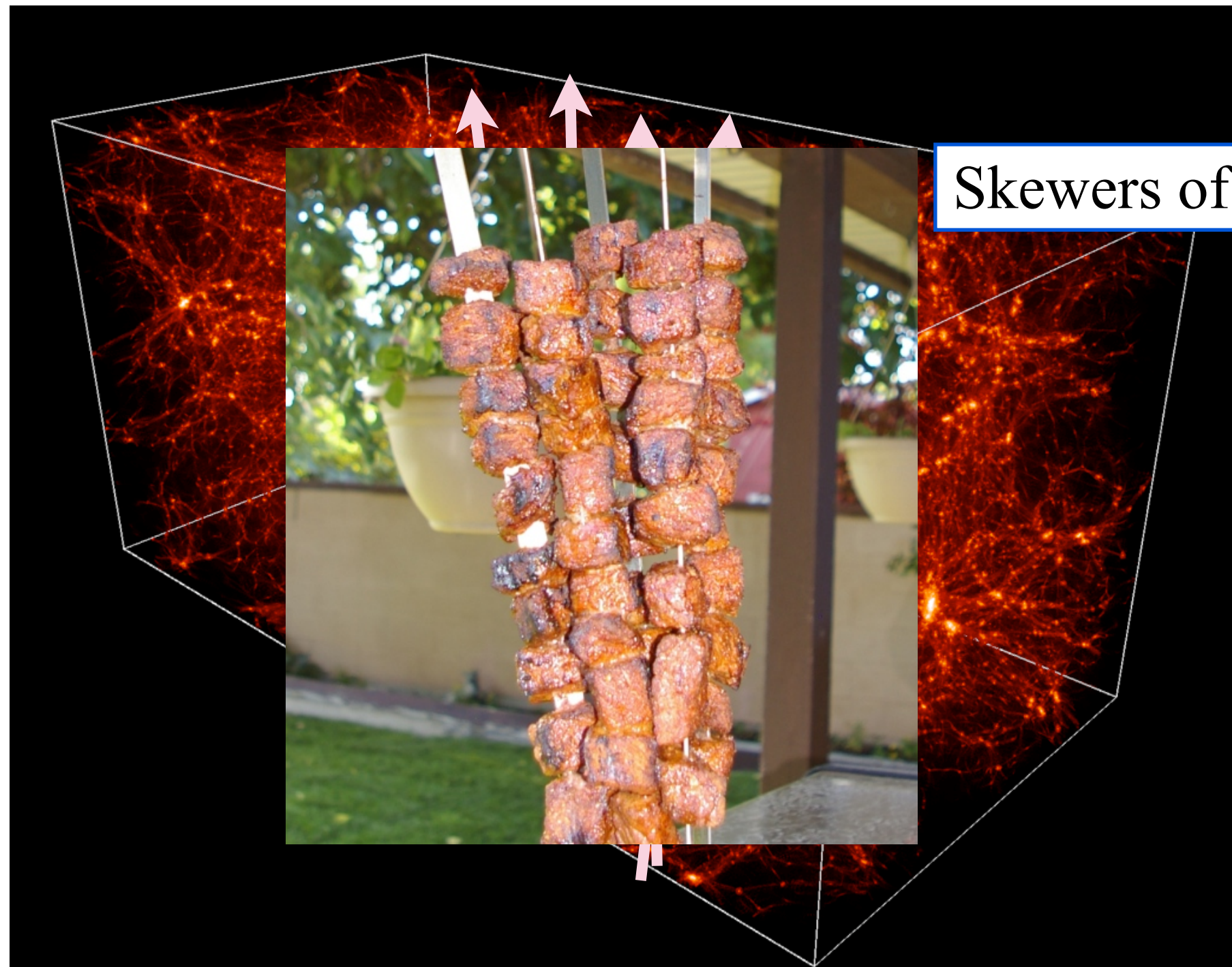
$$\tau = A(1 + \delta)^\beta$$

$$F = e^{-\tau}$$



# Lyman Alpha Forest: what can it do?

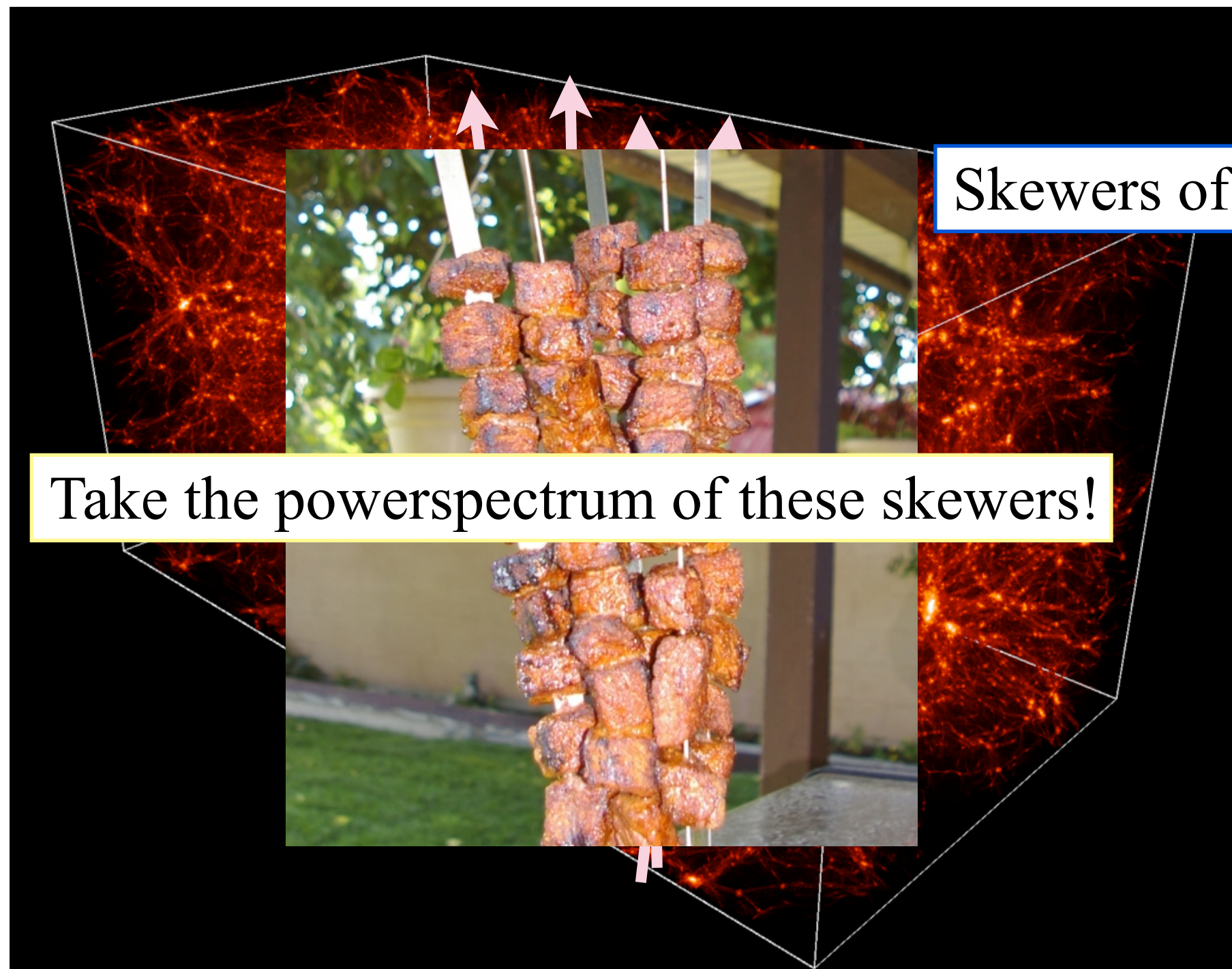
- **Dark Energy via Baryon Acoustic Oscillations**



Skewers of Neutral Hydrogen

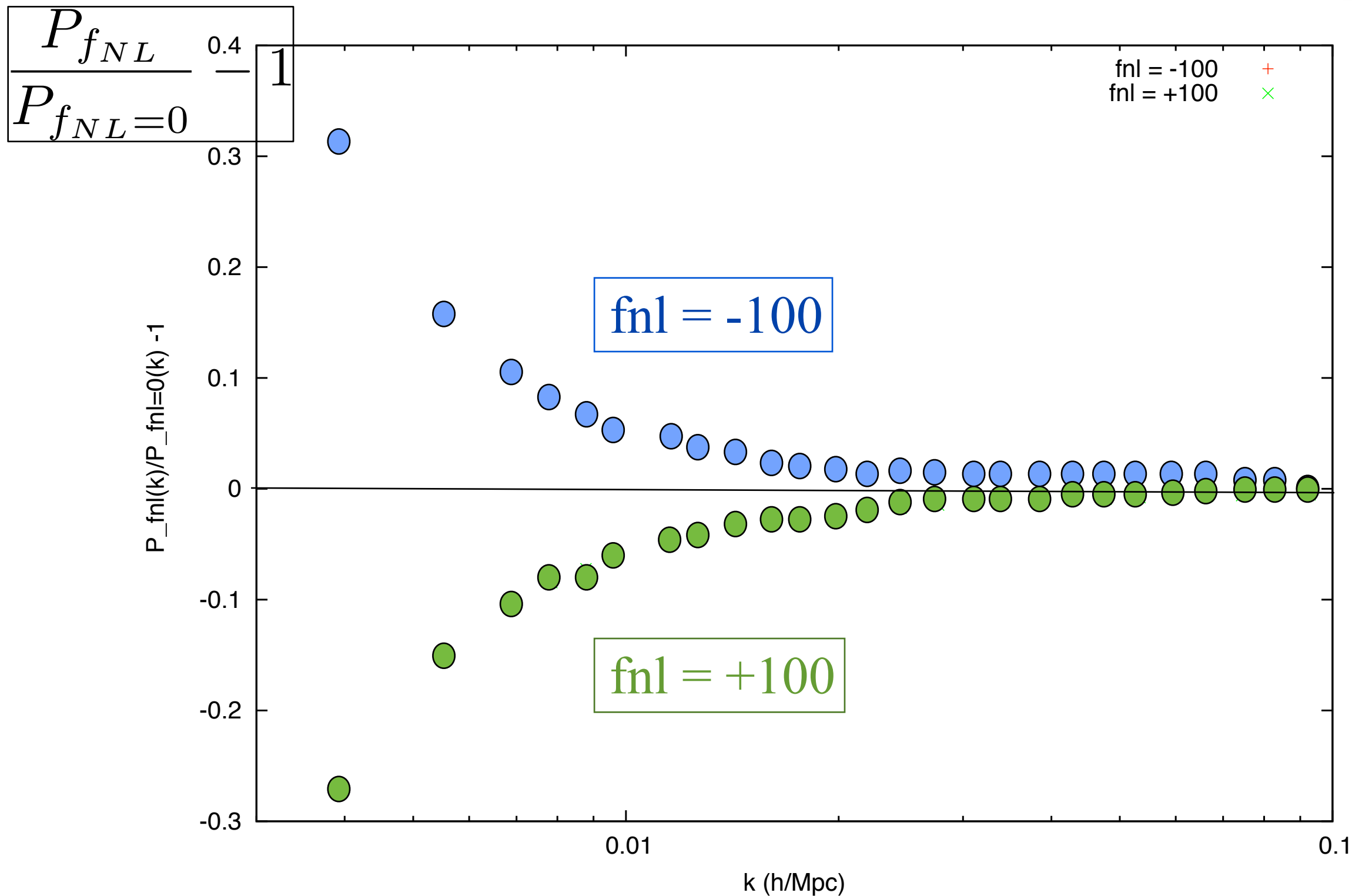
# Lyman Alpha Forest: what can it do?

- **Dark Energy via Baryon Acoustic Oscillations**



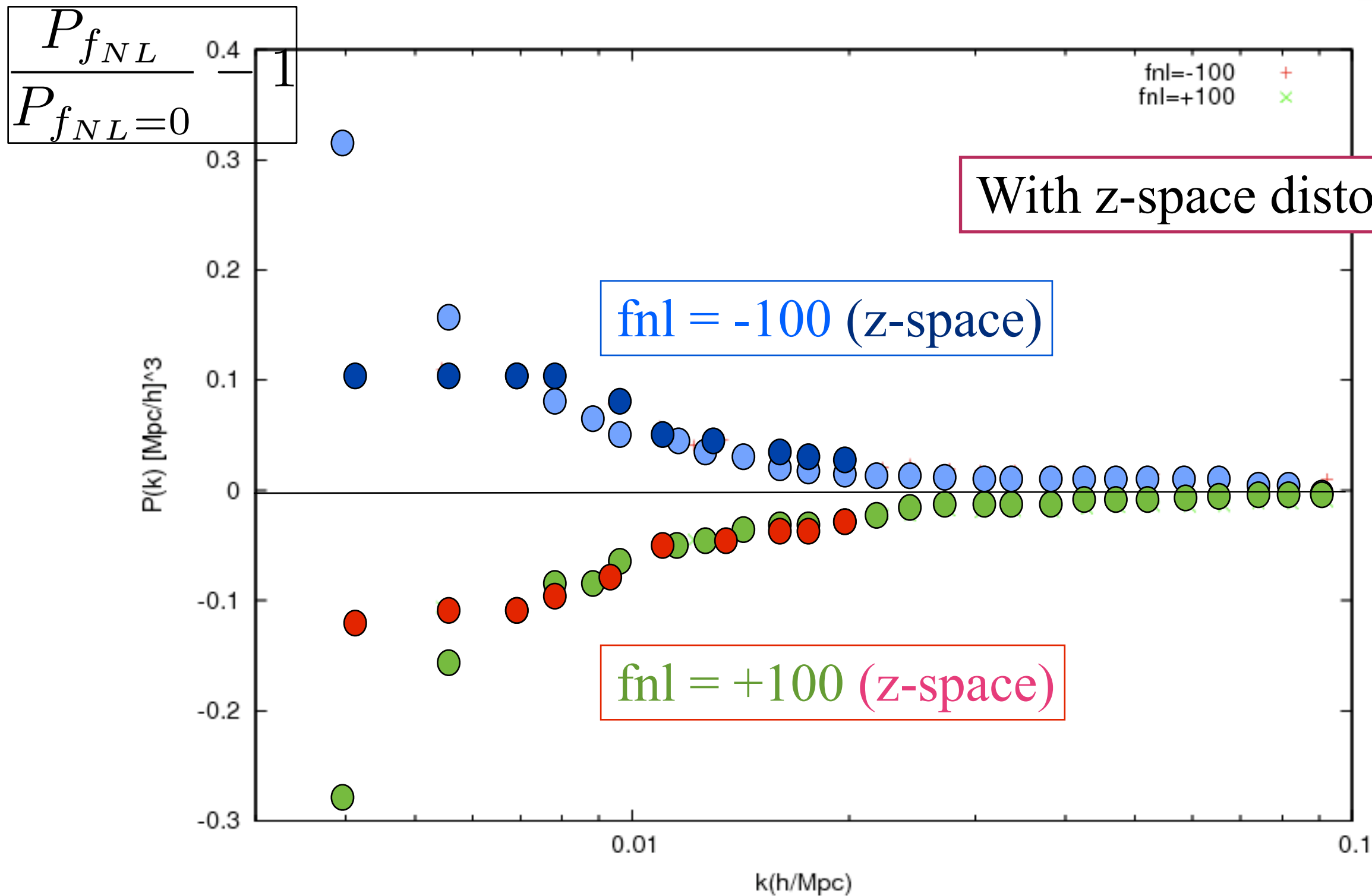


# What can we do with $L_{ya}$ and $f_{nl}$ ?



SH, Slosar, Seljak & Desjacques (in prep)

# What can we do with $L_{\gamma}$ and $f_{NL}$ ?



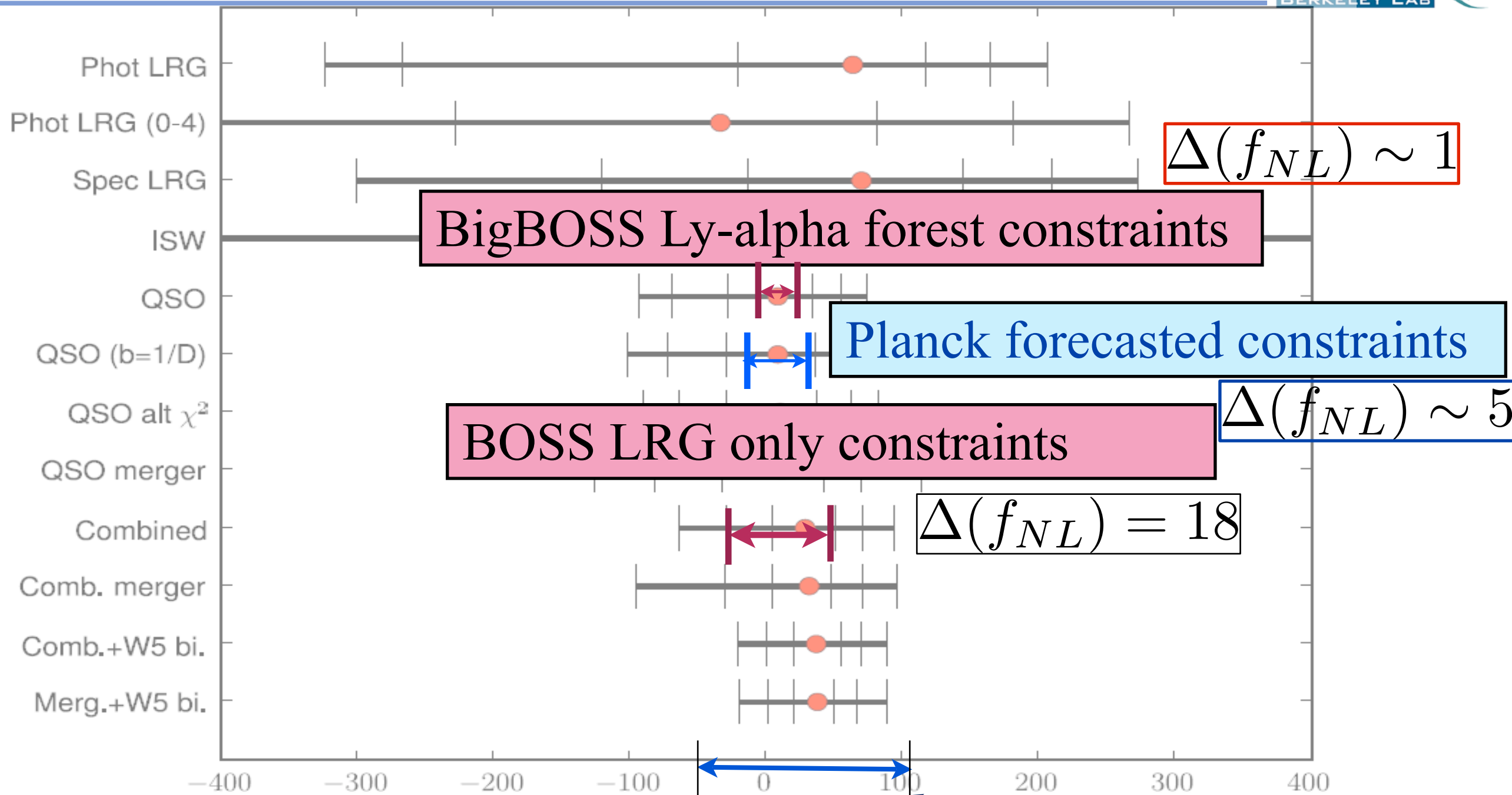
With z-space distortions!

SH, Slosar, Seljak & Desjacques (in prep)



# What can we do with $L\alpha$ and fnl?

## —Non-gaussianities in Early Universe



Best current CMB measurement  $f_{NL}$

canonical  
inflation

curvaton  
models,  
DBI inflation

ghost  
inflation

SH, Slosar, Seljak & Desjacques (in prep)

# Conclusion



- **Lyman-alpha forest in BOSS and BigBOSS will (hopefully) do the following:**
  - **Lya BAO to measure Dark Energy at  $z > 2$**
  - **Lya probes non-gaussianity of the Early Universe**
  - **Other applications:**
    - **Lya  $P(k)$  tighten the cosmological constraints**
    - **temperature density relation in the IGM**
    - **finding missing baryons at higher  $z$**

$$\sqrt{\xi_{lh}^2 / \xi_{ll} \xi_{hh}}$$

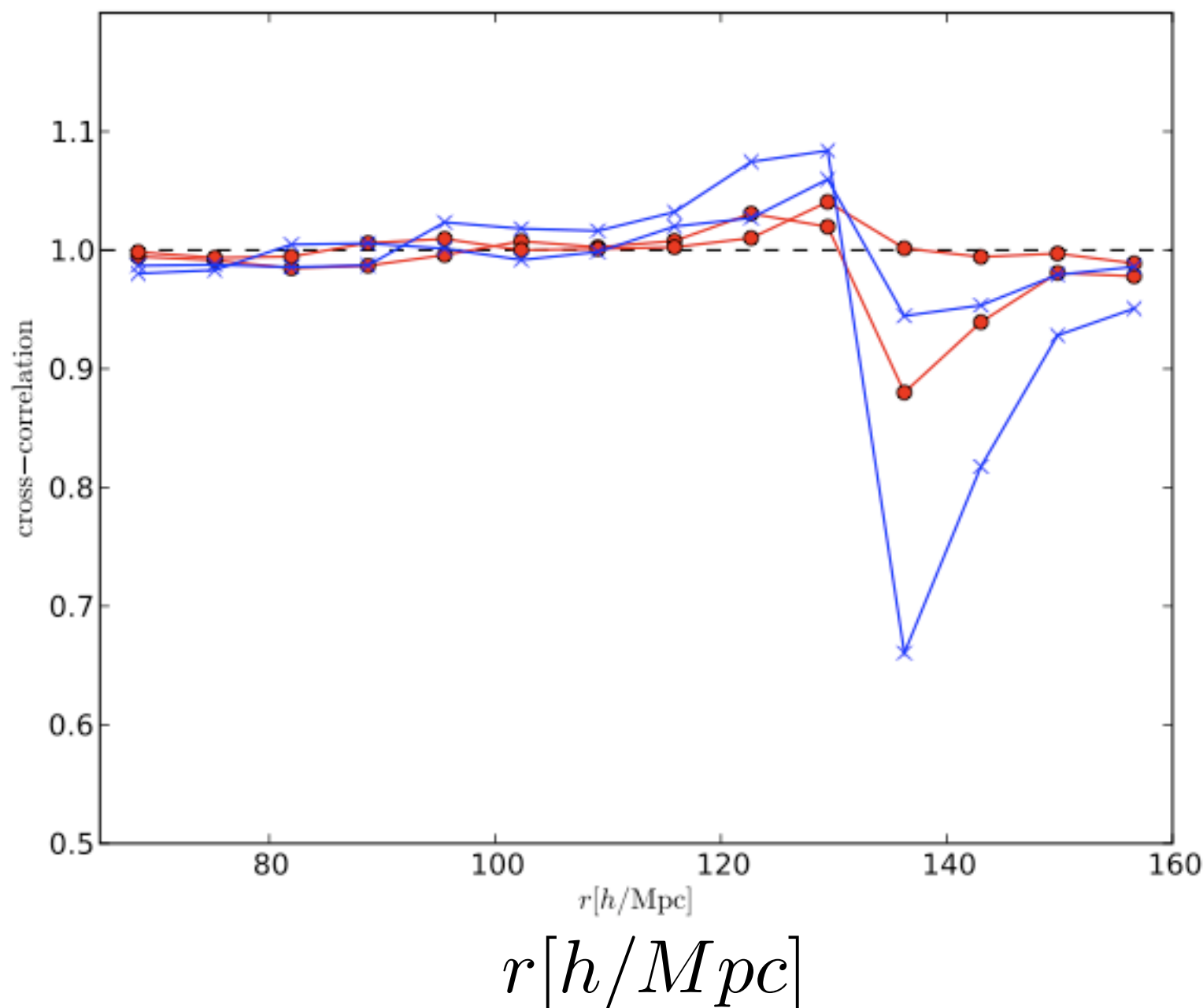
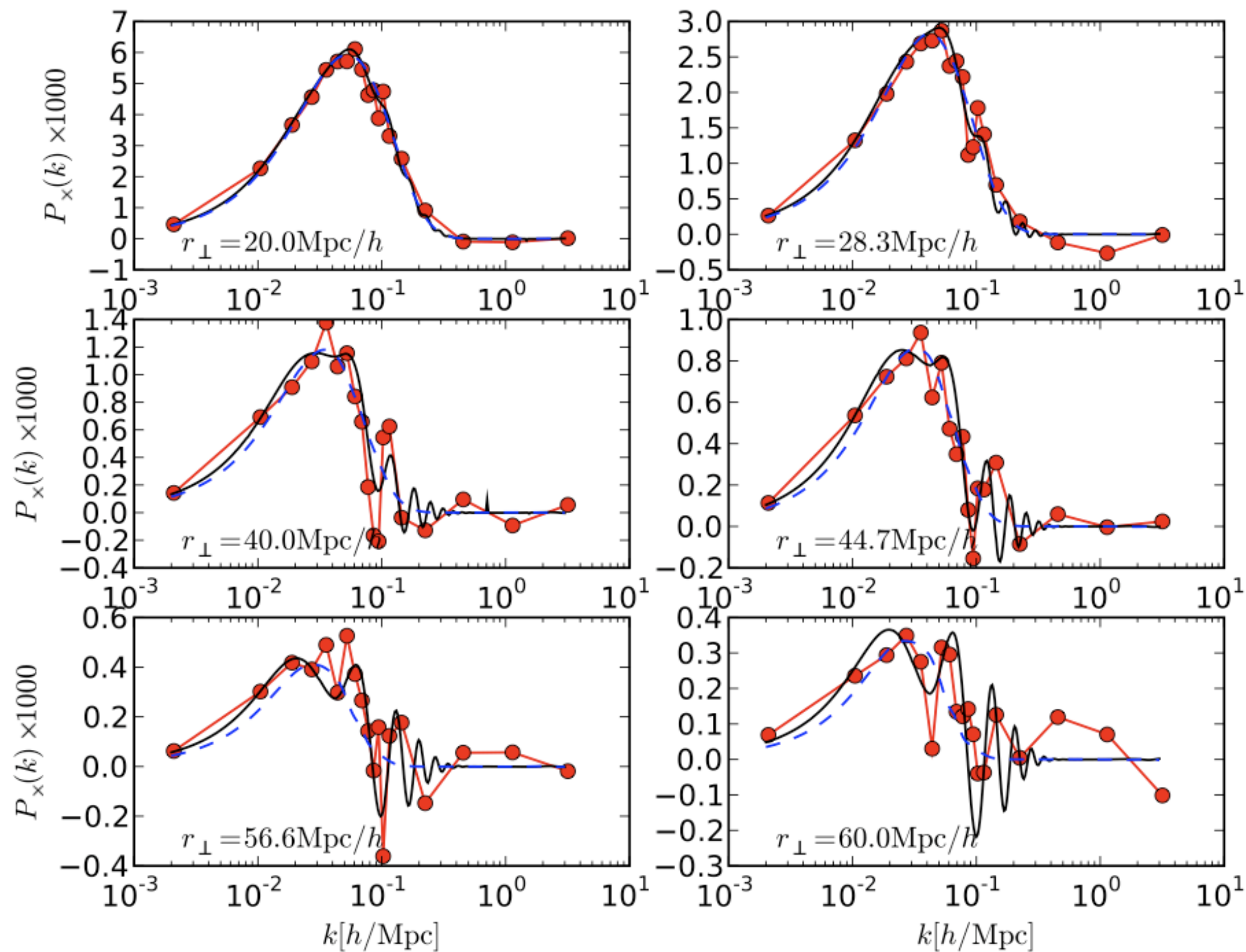


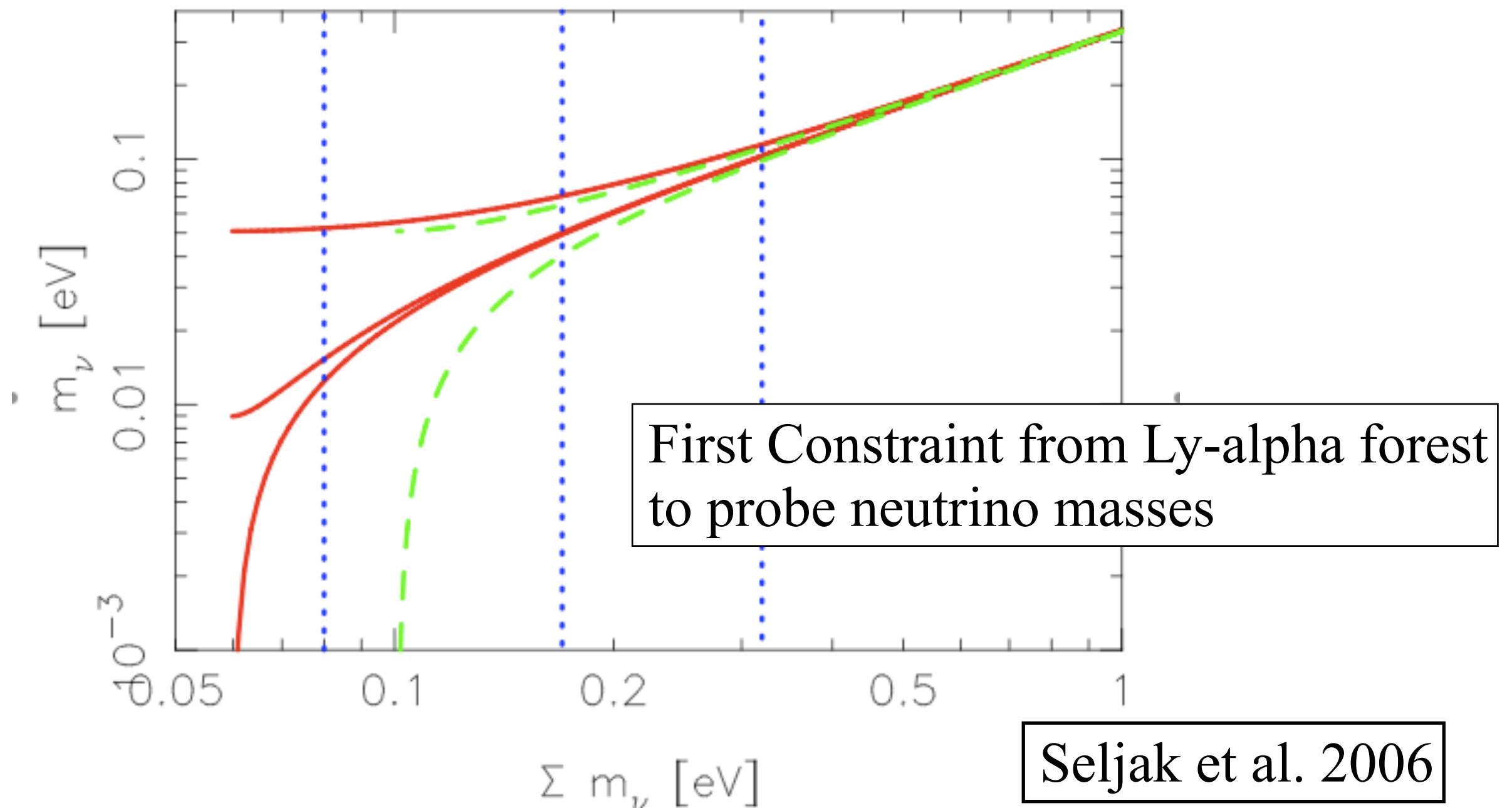
FIG. 2: The cross-correlation coefficient between the flux in our low and high resolution boxes,  $\sqrt{\xi_{lh}^2 / \xi_{ll} \xi_{hh}}$ . Red points show the result for the two low resolution boxes having twice the smoothing length of the high resolution box, blue is the same for  $4\times$  smoothing length.





# Lyman Alpha Forest: what can it do?

- **Cosmological Constraints from Lyman-alpha power spectrum**



Seljak et al. 2006

# Lyman Alpha Forest: what can it do?



- **Cosmological constraints from Lyman-alpha power spectrum (with no BAO)**

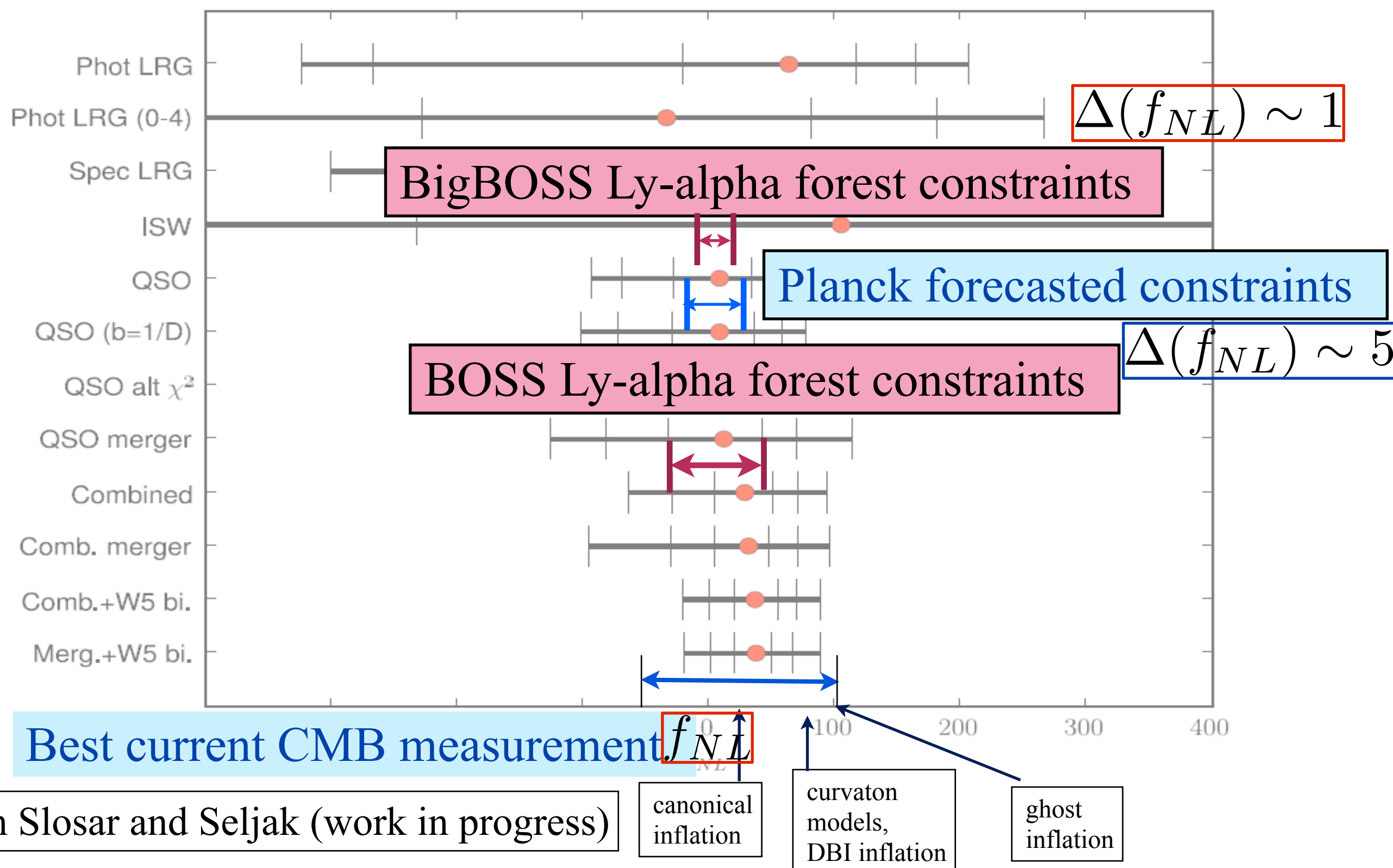
	<b>Planck</b>	<b>Planck + BigBOSS Lya</b>	<b>Planck + BigBOSS Lya + Galaxies</b>
$\sigma(\sum m_\nu)$	<b>0.307</b>	<b>0.048</b>	<b>0.006</b>
$\sigma(\Omega_K)$	<b>0.011</b>	<b>0.0041</b>	<b>0.00038</b>
$\sigma(n_s)$	<b>0.0034</b>	<b>0.0023</b>	<b>0.001</b>
$\sigma(dn_s/d\ln(k))$	<b>0.003</b>	<b>0.0028</b>	<b>0.0005</b>

Courtesy from Anze Slosar

- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations -> Dark Energy**
  - **Lyman-alpha power spectrum**
  - **Non-gaussianities in Early Universe**
- **Conclusion**

# Lyman Alpha Forest: what can it do?

## —Non-gaussianities in Early Universe





- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations -> Dark Energy**
  - **Lyman-alpha power spectrum**
  - **Non-gaussianities in Early Universe**
- **Conclusion**

- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations -> Dark Energy**
  - **Lyman-alpha power spectrum**
  - **Non-gaussianities in Early Universe**
- **Conclusion**

# Lyman Alpha Forest: what can it do?



- **Simulation boxes of Dark matter**

- $3000^3$  particles

- $3000^3$  mesh

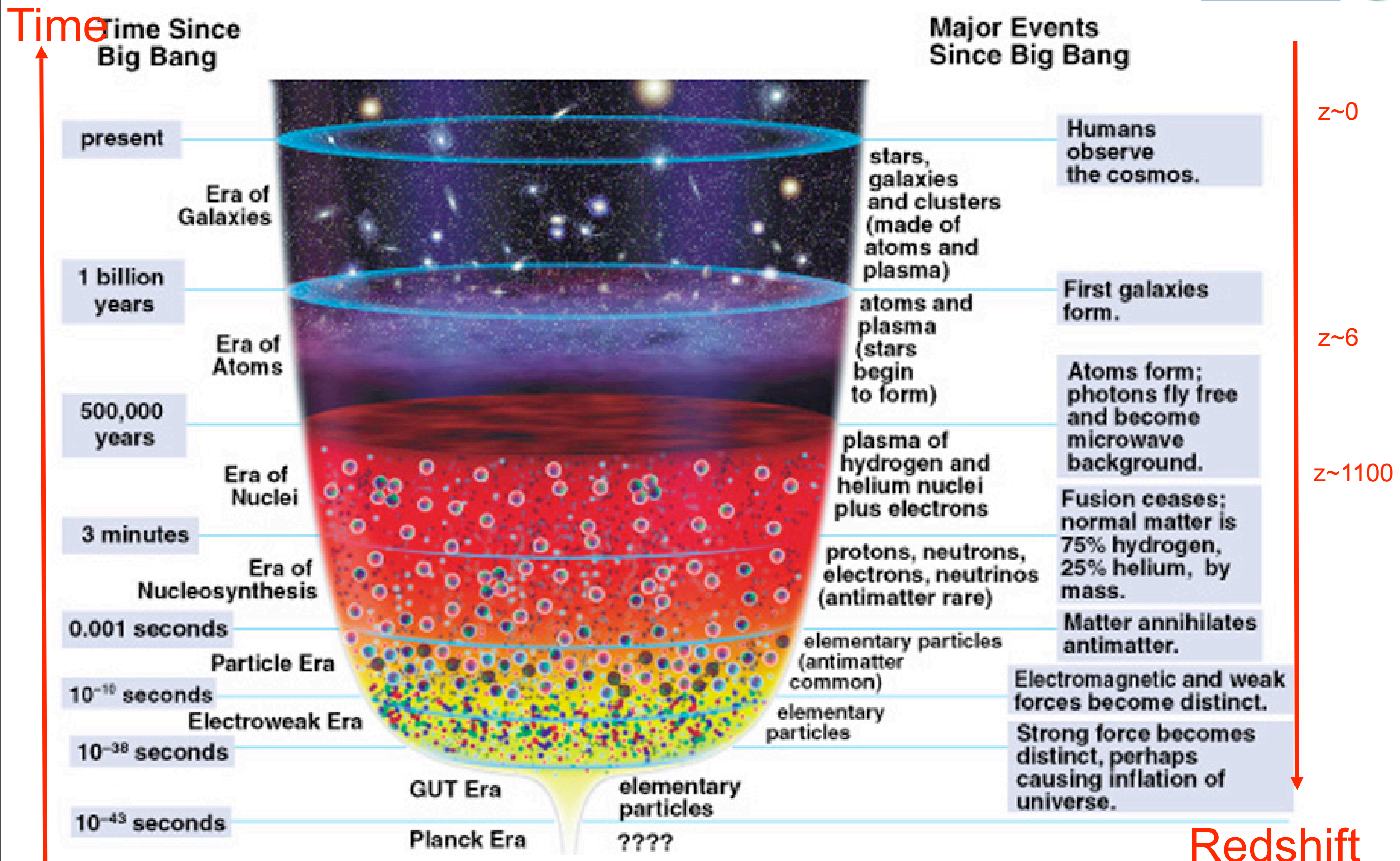
- $1500 (h^{-1} Mpc)^3$  on the side

- $\Omega_m = 0.25, \Omega_\Lambda = 0.75, h = 0.75, n = 0.97, \sigma_8 = 0.8$

**Fluctuating Gunn Peterson approximation**

**Peculiar velocities included**

# Motivations





- **Motivations**
- **Introduction (What is Lyman-alpha forest?)**
- **What can you do with Lyman-alpha forest?**
  - **Baryon Acoustic Oscillations -> Dark Energy**
  - **Lyman-alpha power spectrum**
  - **Non-gaussianities in Early Universe**
- **Conclusion**